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Scope

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e. Words to be printed in italics should be in italics or underlined.
f. Few abbreviations are used in the text of South Carolina Geology. Units of physical measurement (km, m, cm, mi, ft, kg, g) and units of time (Ma, m.y., b.p.) are abbreviated, and abbreviations that are defined in the text may be used.

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IN MEMORIAM

Irving T. Kiff
1932-1992

In October, 1992, the geologic community was saddened by the death of Irving T. Kiff. Irv, as he was affectionately known to his many friends, made substantial contributions to the geologic knowledge of the southeastern United States, particularly the geology of gold mineralization. He attended Old Dominion University, received his bachelor's and master's degrees from the University of South Carolina and did several years of post graduate studies at Columbia University.

During the late 60's, Irv worked for Bear Creek Mining Company in the Knoxville, Tennessee office where he played a substantial role in Bear Creek's pioneering exploration programs in the Piedmont. His empirical observation that gold mineralization in the North Carolina slate belt was clustered around the "sediment-volcanic contact" is still one of the best, if not the best, guide for exploration geologists throughout the length and breadth of the slate belt.

As a graduate student at the University of South Carolina, Irv became aware of sericitically altered rocks near the town of Ridgeway, South Carolina. Later, as an independent geologist, he observed that these typically unimpressive slate belt outcrops near Ridgeway were remarkably similar to rocks at the Haile gold mine near Kershaw, South Carolina. After Irv showed the Ridgeway outcrops to an Amselco geologist in 1979, the company undertook an exploration program that led to the discovery and development of the first new major gold deposit in the eastern United States during the 20th century. Although it often is said that discoveries no longer are made by individuals, Irv certainly deserves the lion's share of the credit for the Ridgeway discovery.

A man of foresight and vision, Irv was part of a small group who recognized the potential of the abandoned Haile gold mine and helped shepherd the redevelopment of the deposit to its present bright future. Thus, he played a key role in the development of the two largest gold mines in the eastern United States. At the time of his death, Irv was Vice President of Exploration for Piedmont Mining Company.

Blessed with an incredible memory, Irv had an encyclopedic knowledge of the literature on Piedmont ore deposits and an almost equal and personal knowledge of slate belt geology, outcrop by outcrop. He was a pioneer in a time of exploding knowledge about slate belt geology and ore deposits, and his contributions have impacted nearly all who were fortunate to know him. Irv surely will be missed.

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COVER PHOTOGRAPH:

"Haile ore body near bottom of Haile pit. Showing foliation and dip. Looking northeast." Photograph from L.C. Graton, 1906, Reconnaissance of some gold and tin deposits of the southern Appalachians, U.S. Geological Survey Bulletin 293.

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THE CAROLINA SLATE BELT AND ITS GOLD DEPOSITS: REFLECTIONS AFTER A QUARTER CENTURY

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Introduction

The history of gold exploration in the Piedmont of the Southern Appalachians has spanned almost 200 years. Chance discoveries of nuggets probably led to placer exploration, perhaps as early as the late 1700's (Pardee and Park, 1948). Placer discoveries were recorded at the Reid farm in North Carolina in 1799 and elsewhere in the Piedmont for the next 20 years. Working of alluvial placers led to nearby eluvial placers in the thick Piedmont residual soils and saprolites, and ultimately to lode discoveries. Small-scale lode mining began in the Piedmont as early as the late 1820's at the Haile and Brewer mines, South Carolina and elsewhere. Lode mining continued at a modest rate more or less continually until all United States gold mines were shut down at the start of World War II. Lode mining did not resume in the post-war years because of rapidly increasing costs and a gold price artificially held at $35/ounce. During the early post-war years, the very thorough and detailed description of Piedmont gold deposits by Pardee and Park (1948) was published, and this volume became the standard reference work on the subject for many years.

Renewed interest in gold exploration in the Piedmont began slowly in 1972 when artifical price constraints were removed and the price of gold increased. Interest has been significant, particularly during the last ten years, although it has never reached the sometimes frenzied levels achieved in some parts of the western United States. The increased exploration activity has been accompanied by significant changes in the ways that Piedmont ore deposits have been viewed. After World War II, and particularly after publication of the Pardee and Park volume, Piedmont gold deposits were viewed as hydrothermal quartz veins, sometimes of limited vertical extent, related in origin to a nearby granitic intrusive. Beginning in the mid-1950's, the volcanogenic theory of origin of sulfide deposits in volcanic terranes began to receive general acceptance in Europe, Canada and Australia (Stanton,1991). It was applied first in the southern Appalachians, to my knowledge, in the middle 1960's and was applied to slate belt gold deposits by Worthington and Kiff (1970). More recent work has led to additional theories on the origin of these gold deposits.

Evolution of Carolina slate belt geology

I first became acquainted with the volcanogenic theory of ore deposits in 1965 from association with A.R. Kinkel, Jr., then with the U.S. Geological Survey. At the time, I was employed by Bear Creek Mining Company in the Appalachian Mountains region. My introduction to the volcanogenic theory led to an exploration program seeking volcanogenic massive sulfides in the slate belt of the southern Piedmont.

At that time, the geology of the Appalachian Piedmont region was less well known and appeared to be much simpler than it seems today. The geologic map included in Pardee and Park (1948, Plate 1) portrayed the entire Piedmont in a few large bands, with the slate belt depicted as one unit (the volcanic series) comprised of volcanics and associated sediments. The term "slate belt" came into common usage after the 1955 publication of P. B. King which divided the Piedmont into geologic "belts" (King, 1955, p. 337-338). The "belt" concept was widely accepted and, although subsequently modified, still is used.

In 1958, a program was started in North Carolina to prepare more detailed maps and to better define the stratigraphy of selected portions of the North Carolina slate belt. These studies were ultimately published by James F. Conley and co-workers and provided the first detailed studies of slate belt geology and stratigraphy. Publication of the Albemarle quadrangle (Stromquist and Conley, 1959; Conley, 1962a) was truly a landmark in slate belt geology. Early stratigraphic studies by Conley and Bain (1965), followed by Stromquist and Sundelius (1969) and Sundelius (1970), formed the basis for much of the future work in the North Carolina slate belt.

About the same time, some detailed studies also were beginning in the South Carolina slate belt. Early quadrangle mapping included the Irmo quadrangle by Heron and Johnson (1958), and was supplemented by the regional studies of Overstreet and Bell (1965a, 1965b). Early stratigraphic studies by Secor and

Wagener (1968) defined units that were broadly similar to those in North Carolina and invited correlation, although subsequent studies (to be discussed in more detail) have made this unlikely.

The dominant concepts about the Carolina slate belt in the mid-60's were summarized by Conley and Bain in 1965 (although there was not uniform acceptance of their stratigraphy). Their concepts of slate belt stratigraphy included the basal Uwharrie rhyolite overlain in regular and predictable succession by a series of sediments and less common volcanics. These units, as shown in Conley and Bain (1965, Figure 2) were displayed in a broad arch or dome called the Troy platform or positive area. This interpretation was initially generally accepted, although it required a thickness of Uwharrie strata of as much as 20,000 feet (Conley and Bain, 1965, p. 121). Such a large thickness of uninterrupted rhyolitic pyroclastic strata over an area perhaps 15 by 35 miles seemed unusual, although not impossible, to some. This large dome, or positive area, surrounded by overlapping sediments, appeared to be a fundamental feature of slate belt geology, and was possibly repeated to the southwest in the outcrop area of the Persimmon Fork volcanics in South Carolina and perhaps the Lincolnton metadacite in Georgia.

The first revision of slate belt stratigraphy after Conley and Bain (1965) was that of Stromquist and Sundelius (1969). Their changes were principally the abandonment of Conley and Bain's Tater Tot group and inclusion of these volcanic units as intercalations within post-Uwharrie sediments (which seems to fit field relationships better). By the mid-1980's, however, changes were afoot that substantially altered some stratigraphic and structural concepts. Le Huray (1987) and Harris and Glover (1988) divided the simple slate belt of Uwharrie lithology domes and intervening sediments into structural blocks of differing ages and fauna. The northernmost slate belt in the area of the Virgilina synclinorium is considered older; in the Albemarle quadrangle, younger; and in the Haile-Brewer area of Persimmon Fork volcanics, even younger and with a different fauna.

Stratigraphic relationships also have been revised considerably (Harris and Glover, 1988). The principal units of the Virgilina synclinorium in southern Virginia are now projected southwesterly from the Virgilina area around the east side of the Uwharrie positive area. These units, however, are projected as underlying the Uwharrie, which is consistent with isotopic ages. It also, however, destroys the positive area except as a topographic feature and transforms the Uwharrie mountainous region into a series of gentle westerly-dipping formations unconformably overlying the older Virgilina units to the east. This has the obvious advantage of eliminating the need for 20,000 feet of Uwharrie strata in the so-called positive area, but is at odds with Conley's mapping in Moore County (1962b). My recollections are that outcrops, and even saprolite outcrops are poor to the east of the Uwharrie mountainous region, but one would expect that these differences are resolvable by more detailed field mapping.

The early studies in North and South Carolina demonstrated that the bounding features of major volcanic units could be mapped in the field. Recognition and definition of these features allowed detailed exploration for volcanogenic sulfide deposits along the stratigraphic tops of rhyolitic pyroclastic units. Unfortunately, no large massive sulfide deposit ever has been found in slate belt strata, to my knowledge, although a few small ones are known. The Bear Creek program was abandoned in 1967, and all subsequent programs by others seeking large massive sulfide deposits also have been unsuccessful. Exploration for massive sulfide deposits in slate belt stratigraphy appears to be a geologic goal that has never achieved much success.

During the Bear Creek program in 1966, however, it was first recognized by Irving T. Kiff that many gold prospects occurred within or close to the outcrop area of the Uwharrie rhyolite. It became evident, rather slowly, I confess, that there might be a relationship between gold prospects and the Uwharrie rhyolite outcrop area. Gold exploration in 1966 was of little interest because of the low gold price, and the correlation remained buried in field notes and an exploration annual report for several years.

Some years later, the data were reviewed and reworked into a publication by Worthington and Kiff (1970). This study initially had little impact on Piedmont exploration, but gradually gained acceptance in the ensuing ten years. It received a substantial shot in the arm in the middle 1970's when William H. Spence added his input to the hypothesis. During the middle 1970's, Worthington, Kiff and Jones were all associated with a joint venture between Cyprus Mines Corporation and the Louisiana Land and Exploration Company seeking massive sulfides and gold within the Carolina slate belt. At North Carolina State University, Spence made a quantum intellectual leap, based on his studies of the Moore County pyrophyllite deposits in North Carolina and subsequently the Haile gold mine in South Carolina. He recognized the non-symmetrical alteration patterns around zones of mineralization and deduced that mineralization must have occurred at the then-existing surface with an alteration zone beneath. He further supported his concepts with mineralogical and geochemical data. His theories eventually resulted in definition of a model deposit described by Spence and others in 1980. This model was modified in an unpublished review by Spence, Kiff and Worthington in 1986 at the annual meeting of the Northwest Mining Association in Spokane, Washington and has continued to be modified since. It has been accepted by other workers (Bell, 1985; Feiss, 1985).

The Spence model became fairly well accepted in the 1980's; but, as time progressed, new concepts were developed, or in some cases old concepts were redeveloped. Several recent studies of Carolina slate belt gold deposits bring genetic thinking almost full circle, and resurrect some aspects of the genetic theories that were prominent after World War II, typified by the studies of Pardee and Park (1948).

"What goes around, comes around" has been said by some, and the changes in thinking about Piedmont gold deposits are no exception. The most recent theories were previewed in the Toronto Gold '86 program (Macdonald, 1986), with its numerous papers dealing with gold deposits in greenstone terranes controlled by post lithification structures and originating in either a "friendly stranger" intrusive at depth or hydrothermal fluids of metamorphic origin. Recent work at the Ridgeway mine (Duckett and others, 1988; Kral, 1989) and at the Haile mine (Tomkinson, 1988; Hayward 1991) describes mineralization occurring in cleavage zones or other structural sites. Other recent work at the Haile mine (Hardy, 1989 and Speer and others, 1992), however, supports the Spence model. Regardless of origin, the exploration industry has done its job well. The exploration efforts over the past quarter century have placed four gold mines into production in South Carolina (Cherrywell and Tockman, 1992). The four mines are the Haile, Brewer, Ridgeway and Barite Hill, all developed or redeveloped in the last eight years. The Ridgeway mine is the largest, although recent developments at the Haile mine suggest that it could become comparable in size. The complete revolution in thinking from the 1950's to the present is remarkable and provides interesting insights into the workings of our science.

Another area of knowledge in which there have been substantial changes and advances is in the discipline of regional tectonics. At the time of King's 1955 paper on the "belt" concept, the entire Appalachian basement was considered to be unknown or partially known Precambrian in various structural arrays from beneath the Valley and Ridge to the Atlantic Coastal Plain. Relationships of slate belt, and other Piedmont sedimentary sequences, to the Paleozoic and late Precambrian sediments of the Valley and Ridge and the Blue Ridge were not known and only occasionally the source of speculation. The great changes, brought about by the advent of plate tectonic theories, has altered concepts about the so-called basement almost beyond recognition. One of the earliest papers (Rankin, 1975), proposing that the Piedmont was partially composed of a slice of Africa, was considered quite radical in some quarters. Only a few years later the COCORP seismic surveys (1983) and a paper by Secor and others (1983) demonstrated that such concepts were becoming generally acceptable; and now few would question them. The very recent review article by Butler and Secor (1991) also includes a discussion of plate tectonic relationships.

Carolina slate belt gold deposits

The changes in genetic thinking about slate belt gold deposits ably demonstrates the variable fashions in geologic thought. Each proponent at the time of presentation of his theories undoubtedly believed he and his colleagues were at the cutting edge of geologic thought and were presenting a theory that resolved many poorly understood geologic relationships. It is sobering how soon ideas can become outmoded and changed! With regard, specifically, to the conformable gold lodes of the Uwharrie terrane and the Haile-Brewer terrane (as defined by Le Huray, 1987), I believe while the circle appears to have gone completely around, there may be reason to question the extent of the revolution. The Haile deposit, in its gross geometry, includes large masses of disseminated, silicified low- to medium-grade gold ore that are more or less conformable (although not perfectly so) to the enclosing, folded, rhyolitic pyroclastic strata. Pyrite may be present as disseminations within or adjacent to the gold ore, or less commonly as small discontinuous massive bodies adjacent to (or below) gold ore. The character of the siliceous pyroclastics and the small massive pyrite lenses have been compared to similar geologic features at certain volcanogenic deposits, although this similarity of features is not agreed upon by all current observers. Argillic alteration, ranging from narrow selvages up to large massive bodies of minerals produced by intense argillic alteration, is often associated with these lodes. Such alteration can occur on both sides of the lodes in deposits that were formed by replacement at shallow depths, but the large massive alteration zones as noted at the Haile mine and the Moore county pyrophyllite deposits always occur on one side only. This suggested to Spence (1975, 1980) that these alteration zones were root zones under deposits being developed at the then-existing surface.

I do not believe that this gross geometry can be interpreted otherwise.

The geologic arguments discussed in recent articles about some slate belt gold deposits (Duckett and others, 1988; Kral, 1989; Tomkinson, 1988) include shear zones that do not conform to stratigraphy, and the presence of pyrite in apparently syn- to post-folding cleavage. There is no disagreement on these points: many gold-bearing zones in slate belt strata exhibit shearing, and there certainly is abundant pyrite on cleavage surfaces. It must be remembered, however, that, regardless of the timing and origins of mineralization, the volcanic strata (probably Cambrian in age) have been through one to several periods of folding and metamorphism. If the mineralization is syngenetic with respect to the enclosing volcanics, then it too has been through this intense tectonism. Small wonder then, that mineralization, as now observed, no longer conforms perfectly to stratigraphy, and pyrite can be observed remobilized into cleavages. Note, however, that some mineralization still follows bedding.

There are many other interesting points regarding these slate belt gold deposits that are gradually becoming better elucidated. Amphibolite-grade and lower-grade metamorphic minerals (e.g. andalusite, pyrophyllite, kyanite, sillimanite) are recognized in some slate belt gold deposits, as well as in deposits that do not contain gold, as a part of alteration zones. Where these minerals are developed in large quantities, they often occur only on one side of the ore, lending further credence to Spence's hypothesis. These minerals originally were interpreted as metamorphic products of argillic alteration raised to higher metamorphic grade, but are noted now by Spence and others (1986) to be advanced argillic alteration minerals similar to those in other near surface epithermal districts, as well as in some porphyry copper deposits (Meyer and Hemley, 1967, p. 171). Another point of interest is the "friendly stranger" at depth, usually one or another variety of the nearly ubiquitous granitic plutons of the Piedmont. This point is considered specifically in the discussion of Worthington and Kiff (1970, p. 534). While one is perhaps rarely many miles from a granitic pluton in the Piedmont, most well documented deposits do not have a closely associated obvious granite or granite porphyry (unless it is part of the host volcanics). I believed then, and still do, that the waning stages of (usually felsic) volcanism including associated intrusives were a much more realistic source of mineralization.

The most recent views (e.g. Duckett and others, 1988; Kral, 1989; Tomkinson, 1988; Hayward, 1992) reject a syn-volcanic source, advance the age of mineralization to syn- or post-metamorphism, and call upon, once again, the familiar "friendly stranger." In this context, one is left with either hydrothermal waters of metamorphic origin, or the late Paleozoic granitic plutons, such as those at Pageland or Liberty Hill in the Haile-Brewer terrane, as possible sources. These plutons as exposed are not notable for widespread hydrothermal effects, nor does their outcrop distribution particularly mimic that of gold deposits. I do not believe that these plutons or any other known plutonic grouping can be related to slate belt gold deposits with any certainty. The waning stage of felsic volcanism, (e.g. Uwharrie, Persimmon Fork, or any other rhyolitic units), is a much better choice as a source. The possibility of syn-metamorphic hydrothermal mineralization is also real, but would require that all alteration be symmetrically disposed around its enclosing fractures, rather than as at the Haile mine or in Moore County, North Carolina. Metamorphic waters also would require a gold source; what better than the adjacent volcanics themselves?

It seems a good possibility, that the origin of slate belt gold deposits may have features of volcanogenic and structurally controlled mineralization. Recent literature on shear zone hosted gold deposits, typified by the Toronto Gold '86 program (Macdonald, 1986), present compelling arguments that shear zone deposits are post lithification, not related to host rock, and deposited in dilatant, structurally controlled loci in a probable metamorphic environment. Examples can be cited in the Superior Province of the Canadian Shield in the Macdonald volume or Colvine, 1989; in the Yilgarn block, Western Australia (Groves, Barley and Ho, 1989) or even in the California Motherlode (Landefeld, 1990). The views of Duckett and others, 1988; Tomkinson, 1988; and Hayward, 1992 also reflect this point of view. It must be remembered, however, that there are also significant gold-bearing districts associated with rhyolites and more particularly rhyolitic flow domes. Examples of these include the Viceroy deposits in the Hart district, Castle Mountains, California (Linder, 1989); the Cactus group of deposits near Mojave, California (Blaske and others, 1991); the Sunbeam deposit in the Challis Volcanics, Idaho (Allen and Hahn, 1991), the Cannon mine near Wenatchee, Washington (Ott and others, 1986), the Hog Heaven district in northwest Montana (Lange and others, 1991) and many others. I believe, therefore, that invoking a rhyolitic unit as a host, precursor, source or at least heat engine is as important as requiring a favorable structural site. Both are important, in varying degrees, as a gold deposit needs a source as well as a site in which to be trapped to become a gold deposit. It in no way stretches credulity to consider that each theory may have some validity. In non-metamorphic environments, gold deposits are often found associated with rhyolitic rocks as in the examples just cited; and in metamorphic environments, as in the Shield area, the California Motherlode and the Carolina slate belt, gold deposits may be found in structural sites, but are sometimes associated with a rhyolitic precursor. In the Carolina slate belt, in particular, many of the major known gold occurrences are associated with rhyolitic strata, and I believe the association with rhyolite is fundamental to their genesis.

It also might be noted that there are also exploration consequences that may result from some of these geologic advances in knowledge. The relationship between gold deposits and Uwharrie or Uwharrie-type rhyolites still is considered valid. The distribution of gold deposits appears to be limited to the Uwharrie outcrop area and to rhyolitic units, sometimes flow domes, intercalated with both younger, and possibly older lithologies. The Russell lode in Tillery strata, for instance, now may be interpreted as related to a large flow dome on strike and slightly stratigraphically lower to the north (Pail and Hart, 1992). The original Worthington and Kiff (1970) Uwharrie-gold correlation now appears overly simplistic, and now I would look for gold associated with rhyolitic domes and pyroclastics of any age in the slate belt. Structurally complex rhyolitic strata, or any deformed strata where a nearby rhyolitic body is known or inferred, also would be more favorable. No quarrel is intended about presence of shearing associated with many gold deposits. Sheared rocks certainly make favorable hosts, but I still believe that a rhyolitic source is required.

The ultimate origin of slate belt gold deposits is still a point of controversy. Recent advocates of structural zone hypotheses certainly have an arguable position, as do the advocates of the volcanogenic hypothesis. These reflections are not meant to resolve the issue, but merely to point out the development and change in working hypotheses and to perhaps guide future speculations.

Discussion

This final paragraph is titled "Discussion" rather than "Conclusions" because it should be obvious that no final conclusions are intended. The growth of knowledge in our day is already almost exponential and one can only speculate on what will be achieved in another quarter century. One can consider the earlier geologic perceptions of the slate belt that were discussed on a single page (Pardee and Park, 1948, p. 16) and are now the subject of a significant part of a symposium volume (Horton and Zullo, 1991). A quarter of a century ago the slate belt was the subject of perhaps a few papers a year and now it is discussed in many journals, symposium volumes and field trip guidebooks every year. Slate belt gold deposits have been considered as hydrothermal veins, parts of volcanogenic systems and, most recently, as being hydrothermally emplaced in shear zones. Each theory has had its ardent proponents, and each has added to our knowledge. Expansion of geologic knowledge can be fascinating for its own sake, and it also may have various industrial applications. The last 27 years have been an exciting time to be a geologist working with slate belt geological concepts. The next quarter century should bring about resolution of some of the problems that now vex us, and undoubtedly will pose equally new and perplexing questions. Let us hope it also may foster discovery of some new deposits!

Acknowledgements

The preceding notes and comments are the result of reflections about Piedmont gold deposits spanning a bit more than a quarter century (1965 to present). Most of these efforts were concentrated in the Carolina slate belt in North Carolina and South Carolina, therefore, these comments are limited to gold deposits in slate belt lithologies. My observations and conclusions always have depended heavily on the astute geologic thought of many colleagues in exploration programs during the above time frame, in particular Irving T. Kiff, William H. Spence and Earl M. Jones. My conclusions, however, are mine, and I accept full responsibility for them. I also wish to thank ASARCO, Incorporated, my present employer; Piedmont Mining Company, present owner of the Haile Gold Mine; and the many others with whom I have been associated for their support and encouragement. The manuscript has benefitted from review by many of my associates, as well as reviews provided by the South Carolina Geologic Survey.

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GEOLOGY AND RECENT DISCOVERIES AT THE HAILE GOLD MINE, LANCASTER COUNTY, SOUTH CAROLINA

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Abstract

The historic Haile gold mine, discovered over 160 years ago, a target of Civil War destruction and the producer of approximately 360,000 ounces of gold to date, has recently become the site of renewed mining activity and exciting discoveries. The present owner, Piedmont Mining Company, Inc., produced 84,712 ounces of gold from 1985 through 1991 and recently announced a current, in place, drilled reserve of approximately 1,000,000 ounces of gold. As much as 640,000 ounces of this reserve may be minable according to an early feasibility study.

Nearly 20 known gold deposits occur in a 3.0 mile-long, 0.5 mile-wide, east-west trending zone that encompasses the mine area. The deposits are hosted by lower greenschist facies, quartzose, sericitic and feldspathic marine metasediments and metavolcanics of the Cambrian(?) Carolina slate belt. Recent drilling has allowed significant modifications to previously proposed genetic models. Original protolith mineralogy, regional metamorphism and supergene weathering are found to explain most of the readily apparent mineral zoning. Wide-spread hydrothermal metasomatic replacement is lacking, except at the relatively small Champion deposit. The gold-rich rocks at the Snake, Red Hill, Haile and numerous other deposits, are high-silica metasediments that probably originated as marine exhalites (chert) and epiclastics (arenites). Marine exhalative pyrite is also common in, and adjacent to, these rocks. In these deposits, gold is found almost exclusively in the fine-grained lithologies. This suggests that exhalative gold mineralization occurred in low-energy environments marked by slow rates of sedimentation, while nearby coarser-grained sediments, that accumulated rapidly, contain little to no gold. Hydrothermal epigenetic silicification of quartzose meta-arenites is called on to explain the explosive-vent breccia at the Champion deposit.

Supergene weathering (argillation), as opposed to hydrothermal alteration (argillization), is found to explain the thick Mineralite® (white, industrial mineral product) deposits which are hosted by low-sericite, pyrite-poor and undeformed feldspar metaporphyries. Saprolite development, here and elsewhere, is shown to be inhibited by sericite-rich, pyrite-rich, fine-grained or highly sheared rocks. Metamorphic recrystallization, folding, cleavage and shear deformation are superimposed on the pre-existing gold deposits.

The deposits are interpreted to be sediment-hosted volcanogenic, with marine exhalative gold and sulfides in chemical and epiclastic sediments, and epigenetic gold and sulfides in near-surface vent breccias. They have been variably recrystallized, deformed and locally remobilized by later metamorphic and tectonic events.

Introduction

The historic Haile gold mine is located in Lancaster County, South Carolina (Figure 1). The mine is located at the updip edge of the Coastal Plain clastic wedge and much of the area still is covered by a thin layer of sediments (Figure 2).

A significant amount of the data presented in this report is derived from industry files and adds substantially to the numerous published accounts. Since 1974, there has been 125,000 feet of diamond core drilling, 230,000 feet of rotary drilling and 70,000 feet of shallow auger and air-tract drilling on the property. Approximately 65,000 drill samples have been analyzed for gold. In addition, there have been numerous geochemical surveys and geophysical surveys that have contributed to our understanding of the area.

The voluminous published and unpublished data of the past 20 years has advanced greatly the understanding of the Haile mine area. The first modern exploration efforts in the area were a regional program conducted by the Bear Creek Mining Company in the 1960's (Worthington and Kiff, 1970) and a drilling program by Cyprus Exploration Company and Louisiana Land and Exploration Company at the mine in the 1970's. This industry-sponsored work produced nu-

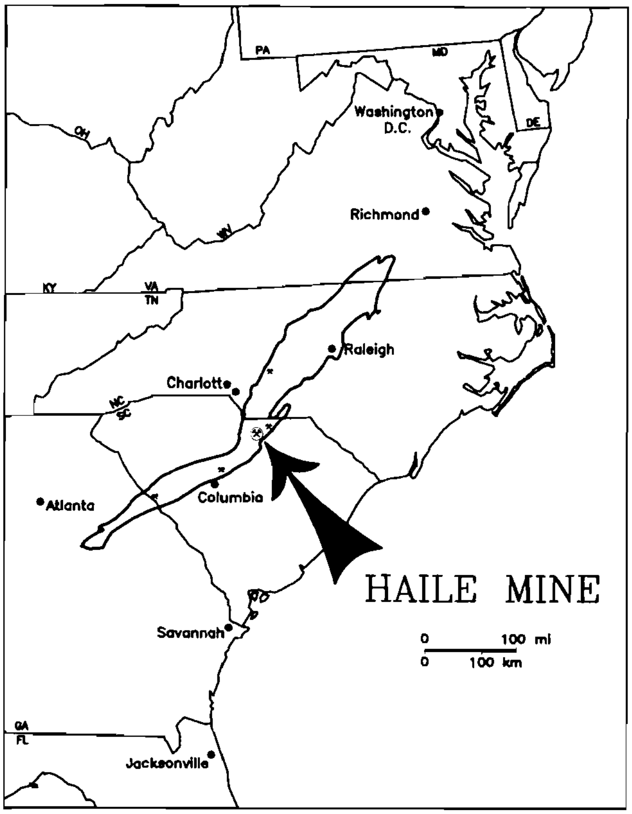

Figure 1. Location of the Haile gold mine, Lancaster County, South Carolina. The enclosed area highlights the Carolina slate belt. Other gold mines shown are: Russell-Coggins (North Carolina); Brewer (northeast of the Haile mine) Ridgeway (northeast of Columbia, South Carolina) and Barite Hill (South Carolina - Georgia state line).

merous reports (Spence, 1975b, 1975c; Kiff and Jones, 1975a, 1975b; Jones and others, 1976; Worthington and others, 1976, 1980; Inman and Jones, 1977; Chapman, 1977; Spence and others, 1980; Cochrane, 1983; and Kiff and Spence, 1988). Regional studies in the 1970's and 1980's by Henry Bell of the U.S. Geological Survey helped to place the mine's rocks and ore deposits into geological perspective (Bell and Popenoe, 1976; Bell, 1980, 1982, 1986; and Bell and others, 1980).

University-related research, principally during the 1980's, relied heavily on geochemical, mineralogical, petrological and structural analyses. Collectively, this work produced major advances in our understanding (Spence, 1975a; Feiss, 1985; Feiss and Slack, 1989; Tomkinson, 1985, 1988, 1990; Al-Otaibi, 1987; Hardy, 1987, 1989, 1990; Secor, 1988a, 1988b; and Hayward, 1989, 1992).

Recent exploration by Piedmont Mining Company, which began in 1983, spurred a new round of extensive drilling and geophysical and geochemical surveys that led to recently identified larger reserves. The more significant unpublished reports are by Cochrane, 1986; Thomssen, 1986; Taylor, 1986; Barnett, 1988; Maddry, 1988a, 1988b; Watkins, 1988; Larson, 1989a, 1989b; Larson and Worthington, 1989; Speer and others, 1990a, 1990b, 1992; Maddry and Speer, 1990, 1992; Maddry and others, 1992; and Piedmont Mining Company, Inc., 1992.

The exciting new discoveries since 1983 give a current, in place, drilled reserve of approximately 1,000,000 ounces of gold. Approximately 640,000 ounces of this total may be minable according to an early feasibility study (AMS Engineering, 1991). Reserve figures used in this report are provided by Piedmont Mining Company, Inc. and are current as of October, 1991. They represent the total in place reserve of gold intersected by drilling and an estimate of the gold minable by conventional open-pit methods. The geological data and gold deposit descriptions presented in this report are current as of January, 1991.

Mining history

Gold was first discovered at the Haile property in stream placers in 1827 or 1828, but interest soon shifted to residual hillside lode deposits and eventually to glory-hole and underground mining. The mine has had a long and colorful history including destruction of the facilities near the end of the Civil War. Production resumed after the war and the mine experienced its most productive period between 1888 and 1908. Mining resumed again in 1936, but operations were forced to shut down by 1942 because of the second World War. Piedmont Mining Company, Inc. resumed gold mining in 1985 and has recovered 84,712 ounces through 1991. Total production from 1827-1991 is estimated at over 360,000 ounces of gold (Table 1).

The mine has produced products other than gold. Sulfur (copperas) and other chemicals were derived from pyrite deposits during the Civil War. World War I saw the production of 8,500 tons of pyrite, also mined for sulfur. Over 400,000 tons of Mineralite®, a white industrial mineral product used mainly as a paint filler, has been mined from three deposits since 1950 (Table 1).

Geology

Twenty gold deposits cluster in a 2.5 mile-long, 0.5 mile-wide, east-west trending zone that encompasses the Haile mine area (Figure 2). Several deposits lo-

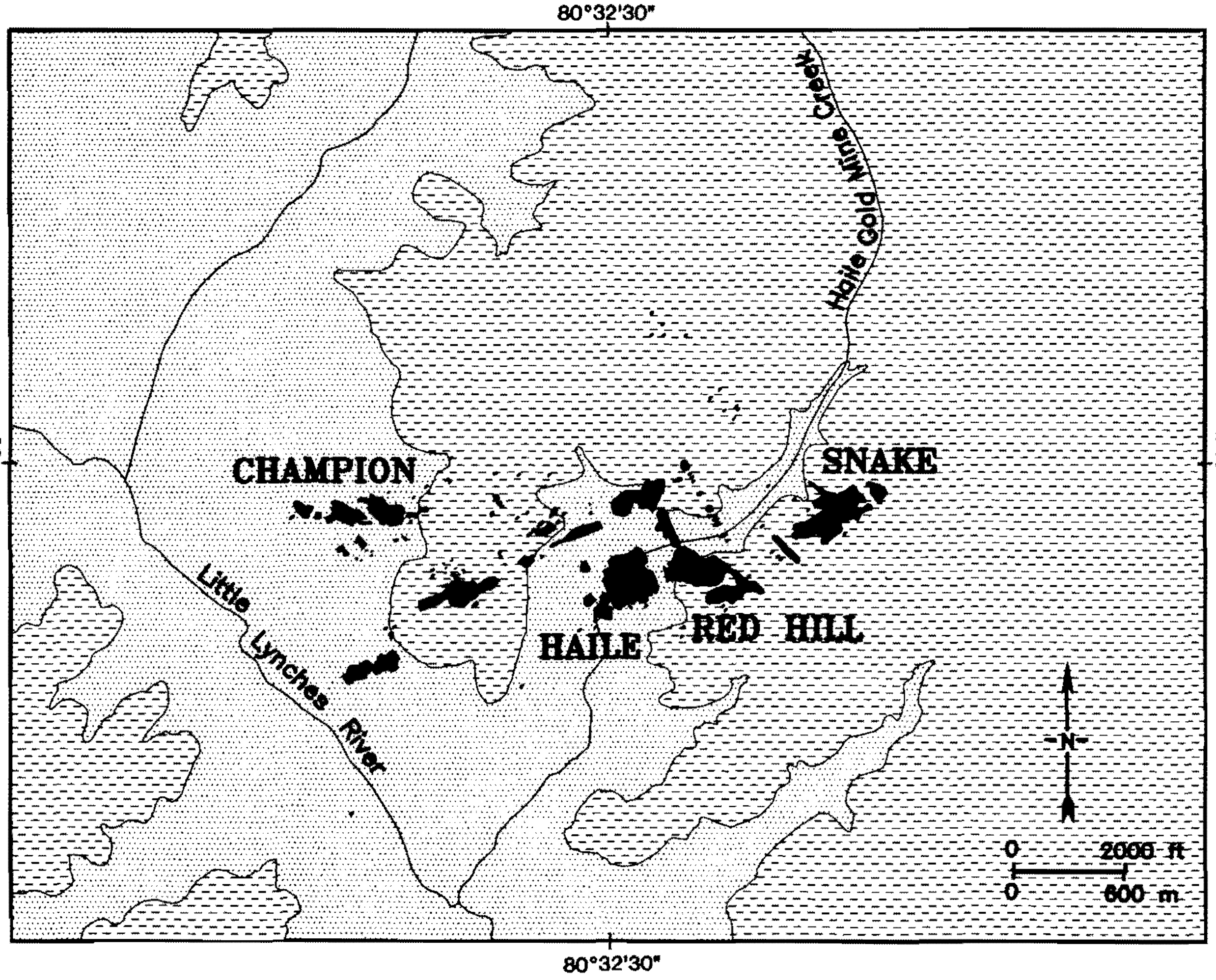

Figure 2. Gold deposits of the Haile gold mine area (Dashes = Cretaceous-Teriary sediments,dots = Carolina slate belt and black = gold deposits).

cated west of Piedmont's property extend the zone to three miles in length. The deposits, which range from a few thousand to a half million ounces of gold each, are hosted by lower greenschist facies marine metasediments and metavolcanics of the Carolina slate belt.

Stratigraphy

The earliest detailed description of rocks in the mine area is found in unpublished industry reports by Kiff and Jones (1975a, 1975b). They describe the rocks as a lower sequence of Cambrian(?) metavolcanics and an upper sequence of metasediments. This general sequence appears to correlate with regionally mapped Carolina slate belt rocks; however, detailed correlation is more problematic. For instance, metasediments appear to correlate with the Richtex Formation and metavolcanics with the older Persimmon Fork Formation, as mapped in the surrounding area by Bell (1980) (Figure 3). More recent work, however, suggests that since the metasediments also are cut by metamorphosed mafic dikes, they probably occur within the top units of the Persimmon Fork formation (Bell and others, 1980; Bell, 1982, 1986; and Hayward, 1992). In other words, detailed mapping at the mine has not located definitively the contact between the Richtex and Persimmon Fork Formations, although the mine sequence may be close to the contact.

The slate belt rocks in the mine area record the

Table 1. Haile mine production.

Year	Gold (ounces)	Silver (ounces)	Mineralite®[6] (tons)	Pyrite (tons)
1827-1828	unrecorded	unrecorded		
1829-1877[1]	49,210	unrecorded		
1861-1865[7]				unrecorded
1878-1880[1]	4,800	unrecorded		
1881-1887[1]	15,000	unrecorded		
1888-1908[1]	149,000	unrecorded		
1915-1917[2]				8,500
1918[3]				unrecorded
1936-1942[4]	60,013	unrecorded		
1950-1984			336,457	
1985	5,517[5]	393[5]	10,491	
1986	11,326[5]	8,442[5]	11,601	
1987	7,836[5]	5,708[5]	11,551	
1988	11,738[5]	6,998[5]	10,782	
1989	15,458[5]	14,535[5]	9,218	
1990	22,320[5]	35,897[5]	8,867	
1991	10,517[5]	28,976[5]	7,579	
164 years	362,735	100,949	406,546	8,500

Sources: 1. Newton and others, 1940; 2. Watkins, 1918; 3. Schrader, 1921; 4. McCauley and Butler, 1966; 5. Piedmont Mining Company, Inc., 1992; 6. Mineral Mining Company, 1992; 7. Bradt and Newton, 1938.

development of intermediate to felsic marine volcanism followed by a quieter period of fine-grained sedimentation. Subsequent Taconic/Acadian deformation records one, and perhaps two, metamorphic events (Secor, 1988a, 1988b). Deformation resulted in the development of a strong northeast cleavage, intense shear zones, broad open folds that plunge to the northeast and locally are overturned, and tight, small-scale folds. Thin metalamprophyre dikes that contain little to no cleavage, were interpreted by Hayward (1992) to have been intruded near the end of deformation. Pennsylvanian-Permian granite plutons were emplaced as a result of an Alleghanian tectonic event, but they occur just outside the mine area. A Triassic-Jurassic(?) diabase dike swarm trends northwest across the mine area and individual dikes cut several of the deposits (Figure 3). Lastly, Cretaceous-Tertiary(?) Coastal Plain sediments cover much of the area (Figure 2).

Rocks from the mine have been dated by four whole-rock methods, as shown below:

LeHuray, 1987		
466±40 Ma	U-Pb	10 area samples
462±53 Ma	Th-Pb	10 area samples
≈455 Ma	Pb-Pb	10 area samples
Eades and others, 1991		
467±4 Ma	Rb-Sr	10 Haile pit siliceous samples
422±4 Ma	Rb-Sr	5 Red Hill pit sericitic samples

LeHuray's ten samples included six massive pyrite samples from Haile mine drill core and four felsic volcaniclastic samples, two of which also came from Haile mine drill core. She concludes that the dates represent original volcanic ages, while Eades and others (1991) attribute their dates to metamorphic resetting.

The gold mineralization at the three largest Haile mine deposits, Snake, Red Hill and Haile, as well as at many of the other deposits, occurs in laminated metamudstone and bodies of fine-grained to cryptocrystalline silica within metamudstone (Figure 3). This suggests a strong stratigraphic control on gold mineralization. Most gold-bearing high-silica rocks have cryptocrystalline, cherty textures and are interpreted to be marine exhalative-chemical sediments, analogous, in part, to the subaerial exhalative sinters proposed by Spence and coworkers (Spence, 1975a, 1975b, 1975c; Spence and others, 1980; and Kiff and Spence, 1988).

A small portion of the gold-bearing high-silica rocks are fine- to coarse-grained, massive, poorly sorted, clastic sediments. They are interpreted to be immature marine quartzose epiclastics, such as arenites and wackes. These rocks also make up much of the adjacent and nearby barren high-silica rocks, seen more clearly in recent drill holes. Their actual source is uncertain, but they may be water-laid, air-fall tuffaceous sediments. They do not appear to be exhalative sediments, although they grade laterally into the gold-

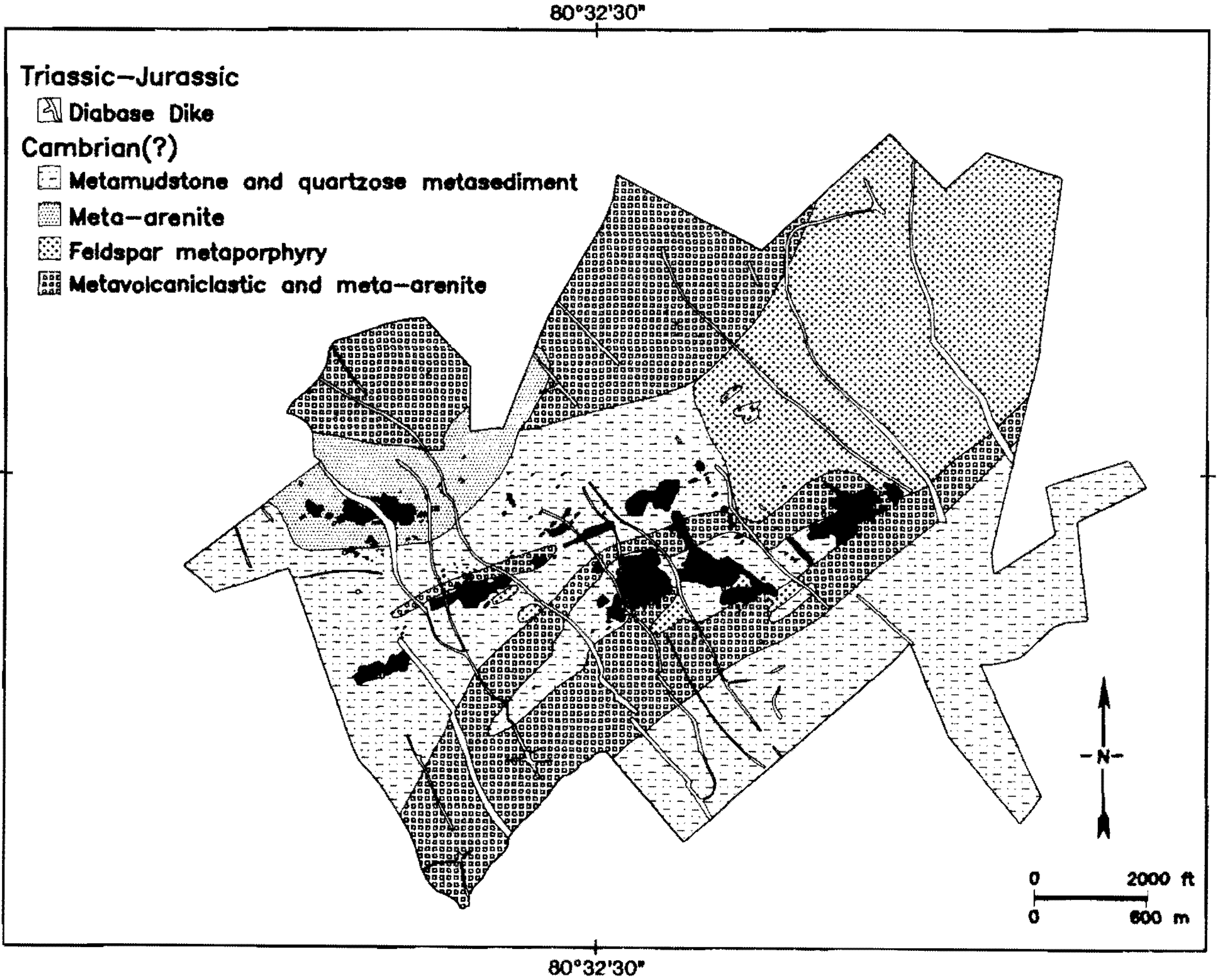

Figure 3. Subcrop geologic map of the Haile gold mine area. The rock types and patterns are based on pit mapping, drill-hole logging, and geophysical surveys. The mapped area is limited to the land holdings of Piedmont Mining Company, Inc.

bearing units described above. Similar quartzose meta-arenites host all of the gold mineralization at the Champion and C-91 deposits.

The metavolcanics, which are seldom gold-bearing, are intermediate in composition (rhyodacitic with little to no free quartz) (Tomkinson, 1985) and range from fragmental pyroclastics to epiclastics, and, possibly, lava flows. Contacts are sharp to gradational between individual units. The metavolcanics consist of a confusing package of crystal tuffs, lithic tuffs, agglomerates, conglomerates, wackes, tuffaceous arenites and plagioclase feldspar porphyries. The feldspar metaporphyries may be tuffs, flows or possibly shallow intrusives(?).

Structure

No discussion of the Haile deposits is complete without mentioning the dramatic occurrence of structural deformation and it's relationship to gold mineralization (Figure 4). Folding and shearing were noted by early workers such as Graton (1906) and Pardee and Park (1948). Thies (1891) presented the first detailed description of the numerous dikes in the mine area. However, the earliest detailed descriptions of shear zones and northeast plunging folds are found in industry reports by Kiff and Jones (1975a, 1975b) and Jones and others (1976). Recent studies have placed new importance on deformation of the mine rocks and suggest syntectonic gold mineralization (Tomkinson, 1985, 1988; Taylor, 1986; and Hayward, 1989, 1992). Barnett (1988), however, found a lack of correlation between intensity of deformation and gold mineralization; a phenomenon we also have observed. We believe, therefore, that the proposed genetic relationship between the two is problematic.

Rocks marginal to the high-silica gold zones at the Snake, Red Hill and Haile deposits exhibit very strong cleavage that parallels the much-weaker regional metamorphic cleavage. These rocks are highly sheared, brecciated and mylonitized. They form tectonites and cataclasites that exhibit strong continuous and closely-spaced cleavage; shearing; extreme pressure solution; transposition of bedding; cleavage-oriented recrystallization of pyrite, silica and sericite; tight to sheared-out small-scale chevron and isoclinal folds; and prominent cleavage-plane mineral stretching in the dip direction of cleavage. The northeast cleavage is the S_1 slaty cleavage of Tomkinson (1985, 1988), and the S_2 cleavage of Taylor (1986) and Hayward (1992). In contrast, the high-silica gold zones contain less-intense structural deformation (Figure 5).

This intense deformation was interpreted as faults and shear zones by Tomkinson (1985, 1988), Cochrane (1986) and Watkins (1988). Hayward (1989, 1992), however, cautions that much of the shearing is only apparent since the mineral stretch direction precludes previously suspected strike-slip movement. He attributes the deformation to pressure solution along closely-spaced cleavage which is deflected around resistant silicified gold zones, somewhat analogous to "mega-boudins" in a foliated rock. We tend to agree with Hayward on the origin of the deformation zones, but we interpret the high-silica gold zones (the "mega-boudins") to be "porphyroclasts" (original material) rather than "porphyroblasts" (newly crystallized material). This essentially reverses the genetic relationship between gold mineralization and deformation.

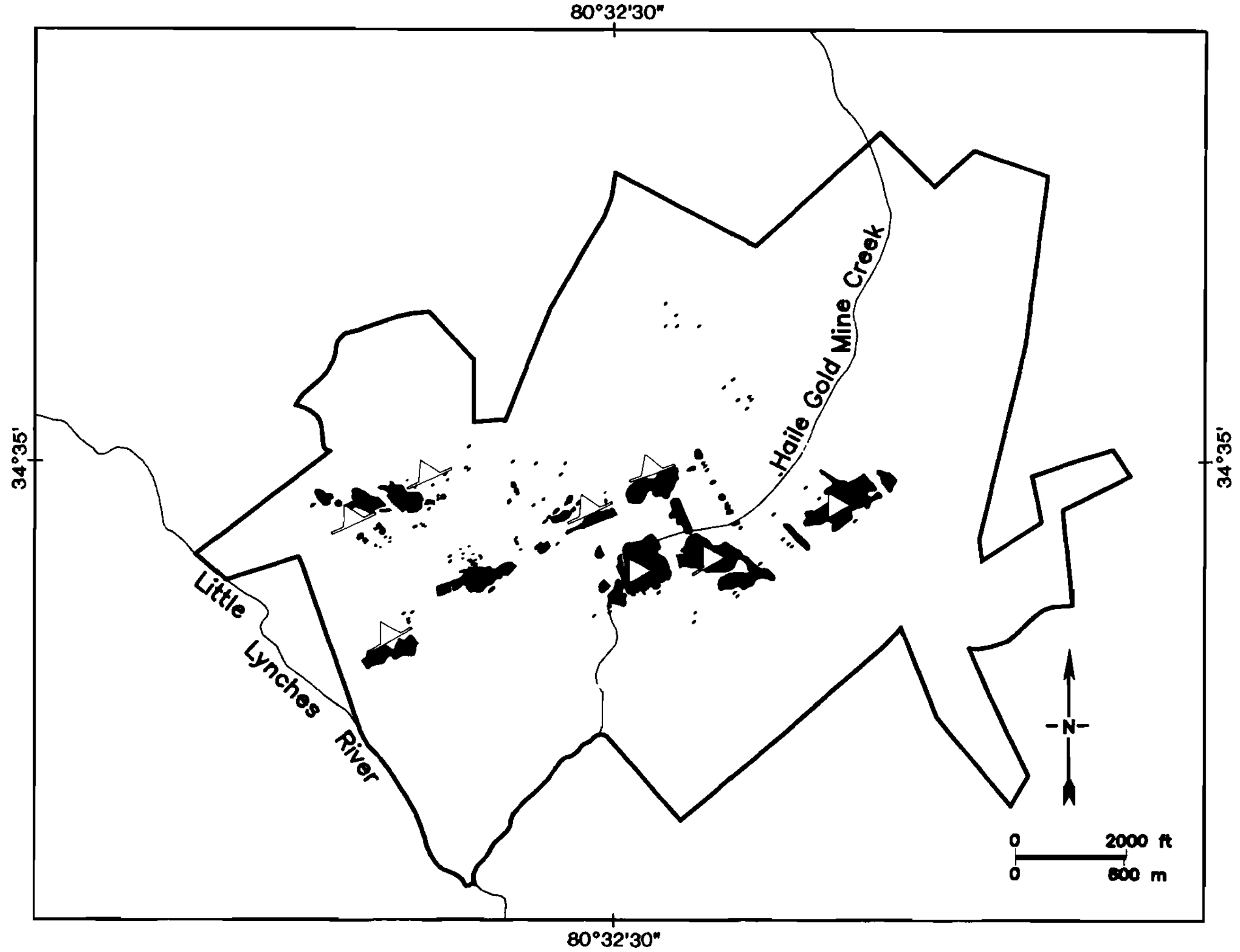

Figure 4. Major deformation trends at the Haile gold mine. The strike and dip directions of zones of intense cleavage, shearing and folding are indicated. The gold deposits are shown in dark shading. The enclosed area is the land holdings of Piedmont Mining Company, Inc.

The role of folding in localizing gold deposits has been proposed recently by Taylor (1986) and Hayward (1989, 1992), who suggest that gold, pyrite, silica and sericite selectively have been moved into the highly disrupted dilatant hinges of parasitic anticlines. Hayward further suggests that folds exist from the thin-section scale up to two-thousand-foot wavelengths. To date, however, no folds larger than a few tens of feet in wavelength have been actually identified in pit exposures or drill data. The only clear folds noted are restricted to bedded metamudstone and metasiltstone. These units often contain abundant small-scale complex folds, but do not themselves appear to be extensively folded. Some of the geologic cross sections recently compiled for the Snake deposit suggest that some larger fold closures may be present, but the evidence is inconclusive (Speer and others, 1990a). The existence of Hayward's (1992) Haile synform has yet to be confirmed by Piedmont Mining Company geologists. Instead, most sedimentary contacts in the Haile mine area consistently dip moderately to steeply to the northwest.

High-angle reverse faults have been observed in the Haile pit and consist of one- to five-foot-thick zones of intensely sheared rock that dramatically displace some, but not all, late quartz veins (Speer and others, 1990a). They are nearly parallel to the dominant northeast cleavage direction and dip similarly to the northwest. Cumulative reverse fault displacement of 20 to 50 feet is suggested in the limited exposure. Geologic cross sections through the Haile and Bumalo ore zones

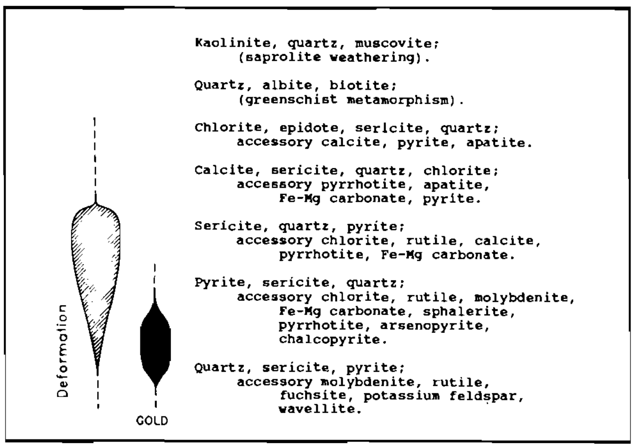

Figure 5. Spatial relationship between mineral patterns, gold deposits and deformation at the Haile gold mine. Saprolite weathering and greenschist metamorphism overprint all other patterns. Modified from: Hayward, 1989; Hardy, 1987; Tomkinson, 1985; Maddry and Speer, in press; Gardner, 1988; and Speer and others, 1990a, 1990b.

suggest that the footwall of the Haile orebody is a high-angle reverse fault and that the Bumalo is a downfaulted extension of the Haile, with a displacement of approximately 400 feet.

Mineral zoning

Figure 5 illustrates the spatial distribution of mineralogy with gold mineralization and degrees of structural deformation. No temporal or genetic relationships are implied. Gold mineralization occurs in high-silica and high-pyrite rocks with accessory molybdenite, rutile and potassium feldspar. Rocks rich in chlorite, epidote, calcite, pyrrhotite and apatite make poor gold hosts.

Although it is tempting to assign some of the mineral patterns to hydrothermal alteration patterns, we advise caution. The observed mineral zoning is greatly influenced by protolith as well as metamorphic and supergene recrystallization. For example, feldspar metaporphyries, which are highly resistant to cleavage development (also noted by Hardy, 1987, 1990), are slightly calcareous where unweathered, rarely contain pyrrhotite or gold, and never have more than a trace amount of pyrite. Likewise, quartzose meta-arenites, which are much more common than previously reported and are locally very susceptible to cleavage development, host quartz veins more frequently than other rock types (also noted by Tomkinson, 1985). These and other quartzose sediments also host the Snake, Red Hill and Haile deposits (as interbeds within the metamudstones) and may explain the presence of large amounts of silica. In addition, recent drilling has encountered fresh, non-sericitized metalamprophyre dikes cutting high-silica gold zones, suggesting that supergene argillation, rather than hydrothermal argillization, accounts for the clay alteration seen in these dikes in pit exposures.

Distinguishing the effects of supergene alteration versus hypogene alteration is difficult elsewhere as well, but new observations suggest that protoliths may hold the answer since we find that saprolite development is highly dependent on protolith mineralogy. In addition, sericite, pyrite and cleavage deformation are inhibitors to saprolite development. Fine-grained protoliths, such as metamudstone and quartzose meta-arenite are very resistant to weathering, even if highly pyritic or highly sheared and produce thin, poorly developed saprolite. The observation that fine-grained protoliths effectively resist supergene alteration suggests that they probably were also poor candidates for hypogene alteration. On the other hand, feldspar metaporphyries are highly susceptible to weathering, especially if undeformed by cleavage. They produce thick, well-developed saprolite, such as the horizon overlying portions of, and extending beyond, the Snake deposit (Speer and others, 1990a), and the high-kaolinite Type II Mineralite® deposits (Maddry and Speer, in press; Maddry and others, 1992) at the Hilltop and Bequelin Mineralite® pits. Offutt (1969) and Gardner (1988) also concluded that these high-kaolinite rocks are supergene in origin. Most previous workers, however, interpreted these rocks to be the result of hydrothermal alteration (Lakes, 1901; Graton, 1906; Pardee and Park, 1948; Worthington and Kiff, 1970; Spence, 1975a, 1975b, 1975c; Spence and others, 1980; Kiff and Jones, 1975a, 1975b; Jones and others, 1976; Taylor, 1986; Hardy, 1987; Hayward, 1989, 1992; Bell, 1980, 1982, 1986; Bell and others, 1980; Cochrane, 1983, 1986; Barnett, 1988; and Kiff and Spence, 1988).

Quartzose metasediments, including metasiltstone, metaquartzite and metachert, host portions, and perhaps all, of the Snake, Red Hill, Haile and other gold deposits. These high-silica rocks probably did not originate by metasomatic replacement of mudstone as proposed by many previous workers (Cochrane, 1986; Hayward, 1989, 1992; Tomkinson, 1985, 1988; Watkins, 1988; Barnett, 1988; and Hardy, 1987, 1990), but appear to be primary siliceous sediments, perhaps recrystallized in place during deformation and metamorphism. These rocks actually may have been partly de-silicified as a result of the loss of silica by pressure solution along cleavage planes during deformation. On the other hand, the Champion gold deposit, hosted by quartzose meta-arenites (Speer and others, 1990a; Dail, 1991) is, in part, silicified and affected by potassium feldspar alteration (Hardy,1987 and 1990). The central core of the orebody consists of a breccia "pipe" that we interpret to be a hydrothermal vent.

Five types of pyrite occur at the Haile mine: Type 1 occurs as thin, fine-grained, undeformed sedimentary beds; Type 2 occurs as extremely fine-grained massive to semi-massive pyrite bodies which often are bedded and appear to be syngenetic; Type 3 occurs oriented along cleavage and shear planes in deformed rocks, often at a sharp angle to bedding; Type 4 occurs as medium- to coarse-grained pyrite intimately mixed with silica and generally lacking an oriented fabric; and Type 5 occurs as isolated cubes, 0.1-1.0 inch across. All types of pyrite may be anomalous in gold; however, cleavage-oriented Type 3 pyrite and unoriented Type 4 pyrite are dominant within the ore zones and appear to be associated with the highest gold values. Thick sequences (hundreds of feet) of Type 1, bedded, pyritic metamudstone have been observed in some drill holes distant to the known orebodies. Type 2 massive to semimassive pyrite is typical of the pyrite-sericite schist seen in the footwall of the Haile, Red Hill and possibly Snake deposits. Type 5 pyrite occurs as porphyroclasts (premetamorphic crystals) and as porphyroblasts (newly grown crystals).

Geochemistry

In general, widespread, readily recognizable, hydrothermal trace element halos are not present around the larger gold orebodies. Molybdenum, silver, arsenic, antimony, tellurium and titanium are anomalously high within the ore zones. In addition, Barnett (1988) noted the enrichment of magnesium, iron and titanium, specifically substituting for aluminum, in phengitic sericites within the East Red Hill gold deposit, located 150 feet southeast of the Red Hill deposit. Silicon, iron and sulfur also are elevated in the high-silica gold zones and, where present, adjacent high-pyrite zones. Bell (1982) noted anomalous tin in sediments from streams draining the mine area. However, only one occurrence of cassiterite was noted by Hayward (1989, 1992) from an area in the Chase Hill pit, which is located 600 feet north of the Haile deposit.

Whole-rock geochemistry of the protoliths is difficult to determine because of the suspected high mobility of potassium, sodium and calcium during diagenesis, hydrothermal alteration, metamorphism and supergene weathering. Tomkinson (1985) avoided the mobility problem by employing a classification scheme utilizing the immobile elements titanium, zirconium, niobium and yttrium. He concluded that the metamudstones are andesitic in composition, in contrast to the dacitic-rhyodacitic metavolcaniclastics. This suggests that the mudstones were not derived by reworking of the volcanics.

Geophysics

Numerous geophysical surveys have been used in the search for new deposits at the Haile mine since the pioneering work of Malamphy in the 1930's (Malamphy, 1937; Bradt and Newton, 1938) (Table 2). Malamphy's autopotential electromagnetic surveys led to the discovery of the Red Hill deposit. Several other Malamphy survey anomalies are located over orebodies later discovered by other methods. Similar self-potential surveys in the 1980's expanded on this technique and led to the discovery of the Snake deposit. The many additional surveys listed in Table 2 have been useful in identifying diabase dikes and zones high in pyrite, silica and sericite. Likewise, contacts and shear zones often are noted first by geophysical surveys.

Drilling

A summary of the exploration and development drilling conducted to date is given in Table 3. Although most early records have been lost, and nothing is known about the first 70 years of drilling at the mine, a total of over 427,000 feet of drilling, exclusive of blast-hole drilling, is documented. The current drill-hole data base contains over 65,000 five-foot and ten-foot intervals individually assayed for gold. The diamond core and rotary drilling since 1983 have led directly to the new expanded reserves and have given a better understanding of the geology of the deposits.

The following sections give a brief review of the largest deposits recently mined by Piedmont Mining Company, Inc.

Snake gold deposit

The Snake deposit was discovered in 1988 by drilling on coincident very-low-frequency (EM-16) and self-potential electromagnetic anomalies (Larson and Worthington, 1989; Larson, 1989a, 1989b; Maddry, 1988b). The deeper extension of the deposit, located northeast of Piedmont's open pit, was discovered by drilling in 1990 (Speer and others, 1990a). The deposit is covered by 5 to 40 feet of Coastal Plain sediments and alluvium (Figure 6).

Piedmont recovered 8,100 ounces of gold in 1989 and 1990 (Piedmont Mining Company, Inc, 1992). The current, in place, drilled reserve is 521,598 ounces of gold in 7,965,833 tons of mineralized rock at an average grade of 0.065 oz Au/ton (AMS Engineering, 1991).

The overall deposit is shaped like a "cigar", or a long flattened cylinder, with moderate dip and plunge (Figure 6). The deposit is approximately 1,500 feet long, 500 feet wide and 150 feet thick. There is significant internal waste within the deposit.

Most gold mineralization occurs strata-bound in non-bedded to thinly-bedded quartzose metasediments such as metachert, metasiltstone and metaquartzite. In turn, these rocks are hosted by thinly-bedded, fine-grained metamudstone. Smaller amounts of ore occur in adjacent coarse-grained metavolcaniclastics such as lapilli tuffs or agglomerates. Minor amounts of gold also are found in nearby deformed porphyritic rocks which may be crystal tuffs, flows or possibly shallow intrusives(?). Metalamprophyre dikes, which have little to no cleavage and are apparently late-tectonic in origin, cut all gold-related features. A saprolite argillation horizon overlies and extends beyond the gold deposit. Saprolite on metamudstone and metavolcaniclastics is generally less than 50 feet thick, while it is as much as 200 feet thick over feldspar metaporphyry. Saprolite often extends as much as 50 feet below the water table and the oxide/sulfide boundary.

The gold-bearing rocks are dominantly silica-pyrite bodies, locally with visible molybdenite. The silica or pyrite content often individually exceeds 70 percent volume of the rock. Most gold occurs as five- to fifteen-micron-size grains of free gold in microfractures and on crystal faces within the pyrite (Honea, 1990). Textures include: bedding laminae, schistosity, fine-grained to cryptocrystalline silica with restricted cleavage development, very fine- to medium-grained pyrite along bedding, and medium- to coarse-grained pyrite in cross-cutting cleavage. Calcite and pyrrhotite do not occur within about 300 feet of the surface and appear to have been removed by deep-penetrating, reduced and acidic supergene fluids. Chlorite is most abundant in rock types peripheral to the gold zones. Sericite is

Table 2. Geophysical surveys conducted at the Haile gold mine.

Year	Survey	Reference
1937-39	Autopotential EM, RESIS, magnetics	Newton and others, 1940
1967	Aeromagnetics (regional)	U.S. Geological Survey, 1970
1973	VLF-EM, magnetics	Kiff and Jones, 1975a
1975	Gravity (state-wide)	Long and others, 1975
1976	Gravity (regional)	Bell and Popenoe, 1976
1977	SP	Chapman, 1977
1984	IP, RESIS, VLF-RES, VLF-EM, SP, magnetics	Wynn and Luce, 1984
????	SP, magnetics	Anzman, 1985
1985	IP-RES, IP-CHAR	Anzman, 1985
1985	VLF-EM, VLF-RES, SP, Crone horizontal coil-EM (CEM), aeromagnetics	Larsen and Worthington. 1989
1988	SP, VLF-EM, VLF-RES, magnetics	Larsen and Worthington. 1989
1989	IP-RES, IP-CHAR	Larsen, 1989a, 1989b
1989	VLF-EM, VLF-RES, SP, magnetics	North American Exploration, 1989
1990	Time-domain EM	Blackhawk, 1990

Table 3. Exploration and development drilling at the Haile gold mine.

Years	Footage	Number of Holes	Company	Drill Hole Numbers	Comments
DIAMOND CORE DRILLING:					
1904-08	unknown	23	HGMC	DDH 1-23	Records lost
1938-39	15,706	66	HGM	DDH 1-66	Records lost
1974-76	11,775	31	CEC	DDH 1-31	
1984	2,487	5	GFM	HD 84-2-6	
1985-90	26,423	67	PMC	DDH 32-98	
1987-88	9,984	37	WMM	NDH 1-37	
1991	58,914	85	AGEI	DDH 99-183	
total	125,289				
ROTARY DRILLING:					
1904-08	unknown	43	HGMC	CDH 1-43	Records lost
1914-18	unknown	28	KMC	CDH 1-28	Records lost
1937-38	4,375	31	HGM	CDH 1-31	Records lost
1988-90	14,273	160	PMC	DB 1-160	
1983-90	175,618	1,303	PMC	RC 1-1303	
1987-90	9,295	54	WMM	NRH 1-54	
1990	3,487	58	PMC	SR 1-58	
1991	25,395	56	AGEI	RC 1304-59	
total	232,443				
AUGER AND AIR-TRACT DRILLING:					
1974-76	39,465	1,566	CEC	AU 1-1573	
1977	10,191	266	CEC	AT 1-226	
1988	2,103	65	PMC	AD 1-65	
1987-88	4,420	90	PMC	CT 1-547	
1989-90	10,380	547	PMC	CT 1-547	
1990	1,620	81	PMC	HAT 1-81	
1990	1,460	78	PMC	SAT 1-78	
total	69,739				
TOTAL	427,471				

Companies: HGMC - Haile Gold Mining Company; KMC - Kershaw Mining Company; HGM - Haile Gold Mines, Inc.; CEC - Cyprus Exploration Company; PMC - Piedmont Mining Company, Inc.; AGEI - AMAX Gold Exploration, Inc.; GFM - Gold Fields Mining Corporation; WMM - Westmont Mining, Inc.

ubiquitous, but occurs in larger volumes within highly deformed rocks adjacent to orebodies.

Small tight folds are present locally in bedded metamudstone and quartzose metasediment. However, larger folds also may be present, but have not been identified clearly. There are several possible large fold closures seen on a few Snake cross sections, but most sedimentary contacts dip consistently to the northwest (Speer and others, 1990a). Weak to strong northeast cleavage is pervasive and dips moderately to the northwest. Deformation increases toward the orebody and reaches a maximum adjacent to the high-silica gold zones. Deformation includes: small, tight folds; sheared-out fold hinges; transposition of bedding; extreme pressure solution; apparent slip displacement; pressure shadow crystal growths; discrete cleavage planes; brecciation; mylonitization; and recrystallization of silica, pyrite and sericite. The dramatic concentration of deformation along the footwall side of the gold zone appears to reflect differences in protoliths.

A syngenetic origin, in part exhalative (cherts) and in part epiclastic (arenites) is suggested by the sedimentary textures, the bedded pyrite and the stratabound geometry. However, internal structural discordancy and the strong spatial association with synmetamorphic deformation, such as cleavage-oriented mineral growths and adjacent intense deformation, suggests possible metamorphic replacement. Both observations could be accounted for by invoking synmetamorphic deformation, recrystallization and remobilization of pre-existing gold-bearing siliceous sediments.

Haile, Red Hill and East Red Hill gold deposits

The Haile deposit originally was discovered during the mining of stream placers in 1827 or 1828 (Bradt and Newton, 1938). Although prospected and mined for

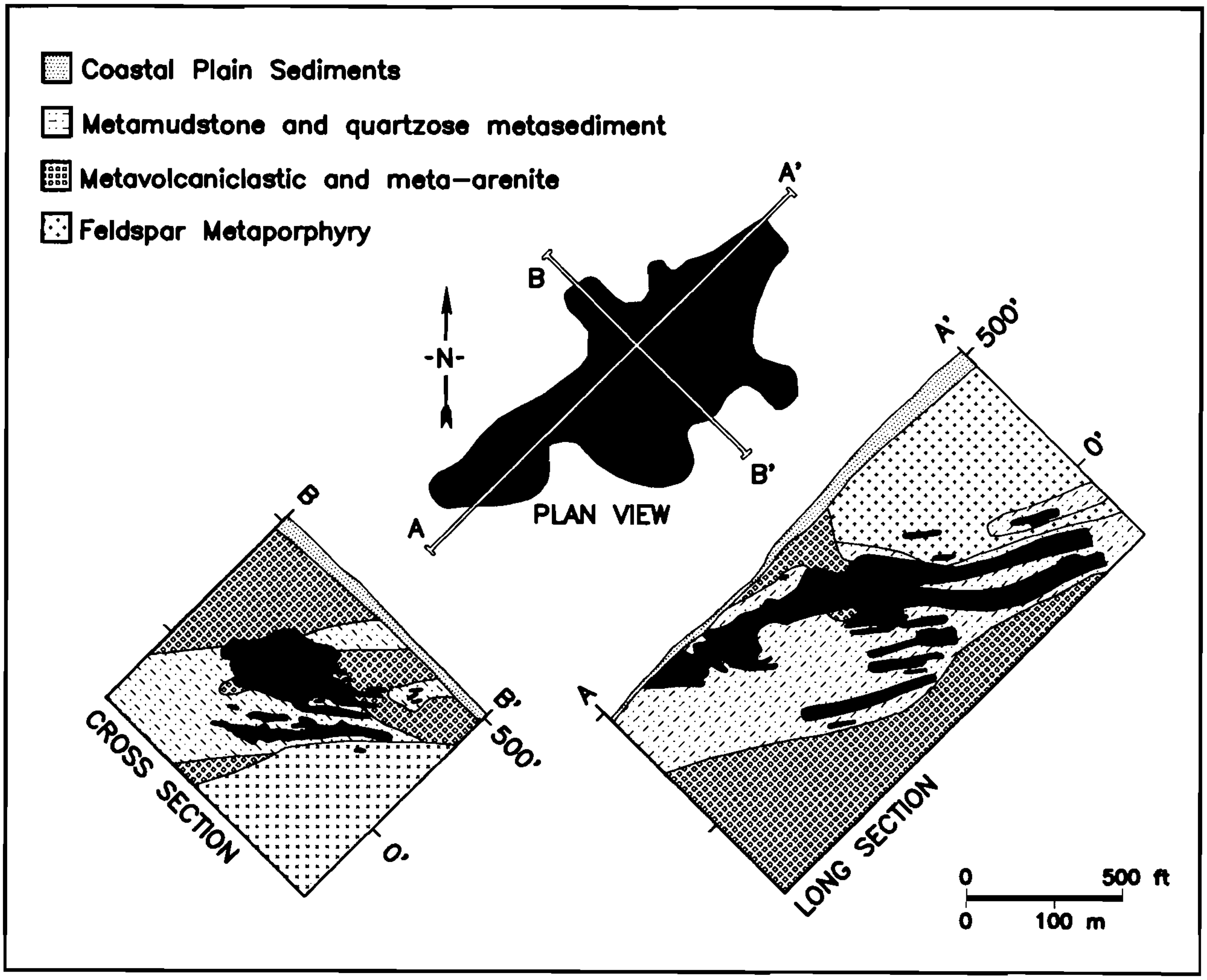

Figure 6. Plan and sectional views of the Snake deposit showing the gold zones in dark shading.

sulfur before 1900, the larger portion of the Red Hill deposit was not discovered until drilling on an autopotential electromagnetic anomaly in 1937 (Malamphy, 1937; Bradt and Newton, 1938; and Newton, 1940). The East Red Hill deposit, which also showed an autopotential anomaly in 1937 (Jones and others, 1976), was not discovered until auger drilling in 1975 (Kiff and Jones, 1975a, 1975b) and was not mined until 1988.

The Haile deposit is estimated to have produced about 200,000 ounces of gold and the Red Hill deposit about 40,000 ounces of gold. Piedmont recovered 2,800 ounces from the East Red Hill deposit in 1988 and 1989 (Piedmont Mining Company, Inc., 1992). The current, in-place, drilled reserve for the three deposits totals 427,399 ounces of gold from 10,270,833 tons of mineralized rock at an average grade of 0.042 oz Au/ton (AMS Engineering, 1991).

The deposits are "cigar-shaped", or long flattened cylinders, with low to moderate dips and plunges (Figures 7 and 8). The Haile deposit is approximately 1,400 feet long, 500 feet wide and 200 feet thick. The combined Red Hill and East Red Hill deposits are approximately 1,300 feet long, 500 feet wide and 100 feet thick. All three deposits contain significant internal waste.

Most gold occurs in thinly-bedded to massive bodies of fine-grained to cryptocrystalline silica within a sequence of thinly bedded metamudstones. However, the East Red Hill deposit appears to be hosted, in part, by metavolcaniclastics. Barren units of coarse-grained metavolcaniclastics and porphyritic metavolcanics are also present. Metalamprophyre dikes, with less cleavage development than the host rocks (late-tectonic) and undeformed Triassic-Jurassic(?) diabase dikes, cut all gold-related fabrics. Saprolite is thin to nonexistent on metamudstones, quartzose metasediments and metavolcaniclastics, but is as much as 100 and 200 feet thick, respectively, over the feldspar metaporphyries located: a) between the Red Hill and the East Red Hill deposits; and, b) in the Hilltop pit, which is located 300 feet southeast of the Haile deposit.

Mineralized rock textures, structures and origins of the three deposits are believed to be the same as those for the Snake deposit.

Champion and C-91 gold deposits

The Champion and C-91 deposits were discovered in 1988 by drilling on a 0.5 to 3.0 parts-per-million gold soil anomaly (Maddry, 1988a). Earlier work consisted of an autopotential anomaly detected in 1937 (Kiff and Jones, 1975b), anomalous gold in auger holes in 1975 (Kiff and Jones, 1975b; Jones and others, 1976) and anomalous gold in a diamond core hole drilled in 1976 (Jones and others, 1976).

Piedmont recovered 31,688 ounces of gold from the Champion deposit and 2,460 ounces of gold from the C-91 deposit from 1989 to 1991 (Piedmont Mining Company, Inc., 1992). These deposits have no current reserves and await additional drilling.

The Champion deposit contained an up-right funnel-shaped breccia body approximately 100 feet across at the surface that tapered to 10 feet in diameter at approximately 150 feet below the surface (Figure 9). This apparent breccia "pipe" constituted a high-grade gold core that averaged 0.20 oz Au/ton and was surrounded on three sides by a 400-foot-wide halo of discontinuous mineralization that averaged 0.02 oz Au/ton. The C-91 deposit was similar to the Champion but lacked the high-grade breccia body.

The host rocks are quartzose meta-arenites (Speer and others, 1990a; Dail, 1991). The breccia body occurred in a fine-grained metaquartzite. Adjacent units, which contain only lower grades of mineralization, include fine- to medium-grained metaquartzites, metawackes and meta-arkoses. Black metachert nodules in the metasediments also have been noted (Dail, 1991). Several barren dikes are present, including a 150-foot-wide diabase dike of Triassic-Jurassic(?) age that separates the Champion deposit from the C-91 deposit (Figure 9), and several one- to three-foot-wide metalamprophyre dikes. Saprolite thickness is highly variable, but locally reaches a maximum of only 30 feet. The oxide/sulfide boundary occurred at a depth of approximately 100 feet.

The siliceous breccia "pipe" consisted of angular, matrix-supported fragments of the host rock. Individual clasts showed slight (crackle breccia) to significant displacement. A stockwork of quartz veins characterized the lower-grade zone peripheral to the breccia. Disseminated and fracture-hosted pyrite, with lesser molybdenite, occurred throughout, while traces of chalcopyrite and sphalerite were present at the bottom of the "pipe". Wavellite, a phosphate mineral, was locally abundant. Rare occurrences of large calcite crystals, intergrown with quartz and later leached away, were observed within the breccia. White potassium feldspar occurred in the breccia matrix and as disseminations or bands within the surrounding quartz veins (Hardy, 1989; Dail, 1991).

Northeast cleavage and related zones of intense shear deformation were present throughout, but were developed best outside the breccia "pipe". At least locally, host rocks are dipping steeply to the northwest and may be overturned to the southeast (Dail, 1991).

The Champion and C-91 deposits are significantly different from the Snake, Red Hill and Haile deposits and apparently have a different origin. The presence of a well-developed breccia "pipe" and a surrounding hydrothermal halo, suggest an epigenetic explosive vent perhaps related to volcanic activity.

Discussion

Numerous theories have been proposed to explain the origin of gold deposits at the Haile mine. However, many past observations have apparently been hindered by the lack of exposures and limited access to the geochemical, geophysical and drilling data. Based on the recent mining and exploration, and coupled with useful contributions from earlier studies, we have developed the following working hypothesis:

1) All gold deposits appear to have been originally emplaced in sediments by hydrothermal and sedimentary processes during the final stages of Cambrian(?) volcanism. They have been variably deformed, recrystallized and even locally remobilized during regional metamorphic and tectonic event(s).
2) At least one deposit (Champion) appears to have been originally epigenetic and may have been the site of an explosive hydrothermal vent with a surrounding alteration halo.
3) Most other deposits (specifically the Snake,

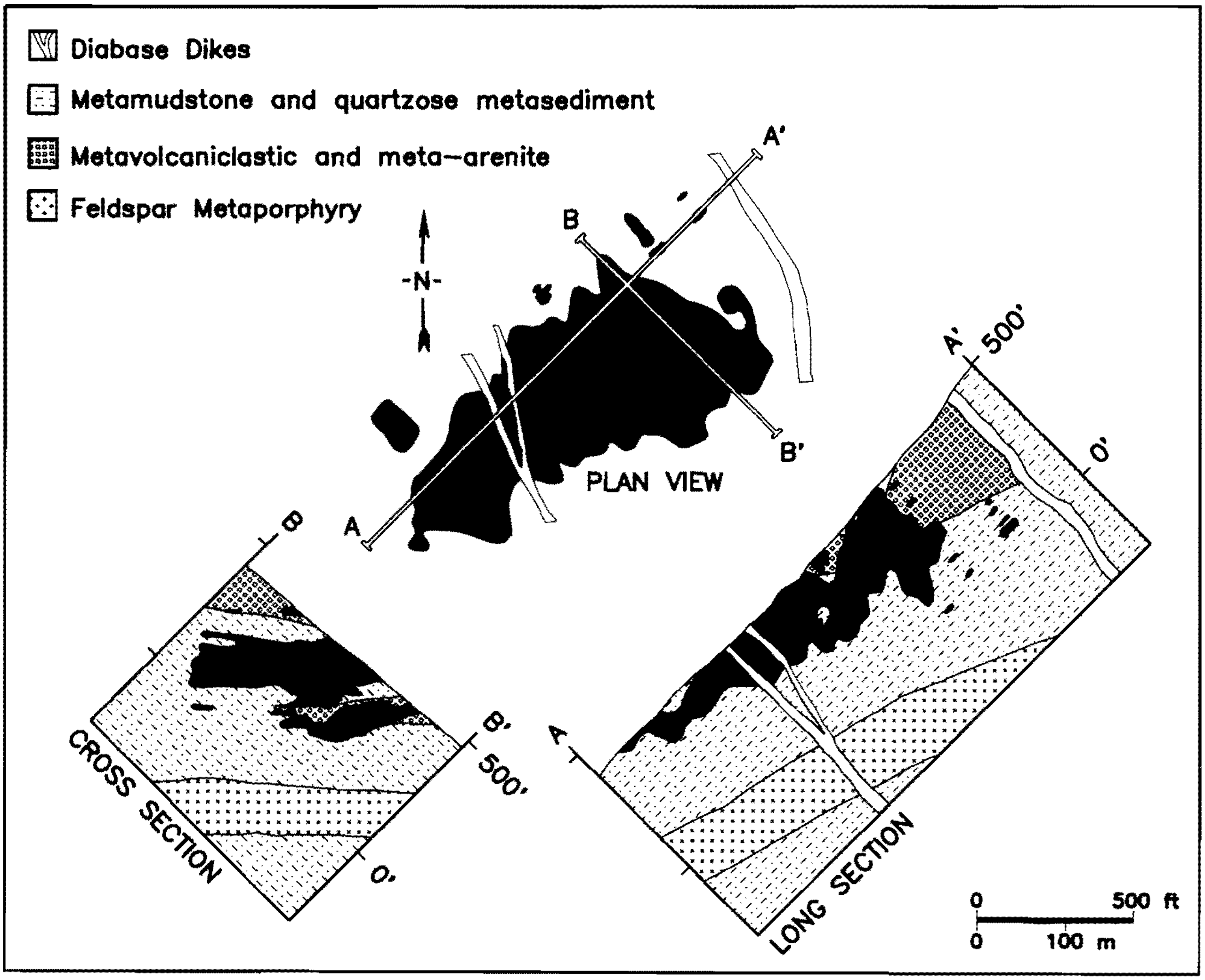

Figure 7. Plan and sectional views of the Haile deposit showing the gold zones in dark shading.

Red Hill and Haile) appear to have been originally exhalative and may represent gold-bearing siliceous marine sediments. These deposits are strongly stratibound (representing original sedimentary deposition) yet exhibit some dramatic internal discordancy (representing metamorphic recrystallization and remobilization).

Our working hypothesis has much in common with, and only slightly modifies, previously proposed volcanogenic models, and in light of the more recently recognized importance of structure, we would classify the deposits as:

recrystallized, and locally remobilized, sediment-hosted volcanogenic; with exhalative gold and sulfides in marine chemical and epiclastic sediments, and epigenetic gold and sulfides in near-surface vent breccias.

In the search for new ore deposits, the correct identification and use of guides to ore can obviously lead to dramatic success. At the Haile, as at other similar mines, our most useful guide to ore is the detection of gold in drill holes. The selection of drill sites and drill depths, however, is governed by the more difficult job of identifying and projecting favorable stratigraphic units, structural trends, geophysical responses, mineral zoning and geochemical patterns (including gold mineralization). Recent geologic logging of new drill holes has given a clearer framework in which to incorporate the observations of previous workers. In

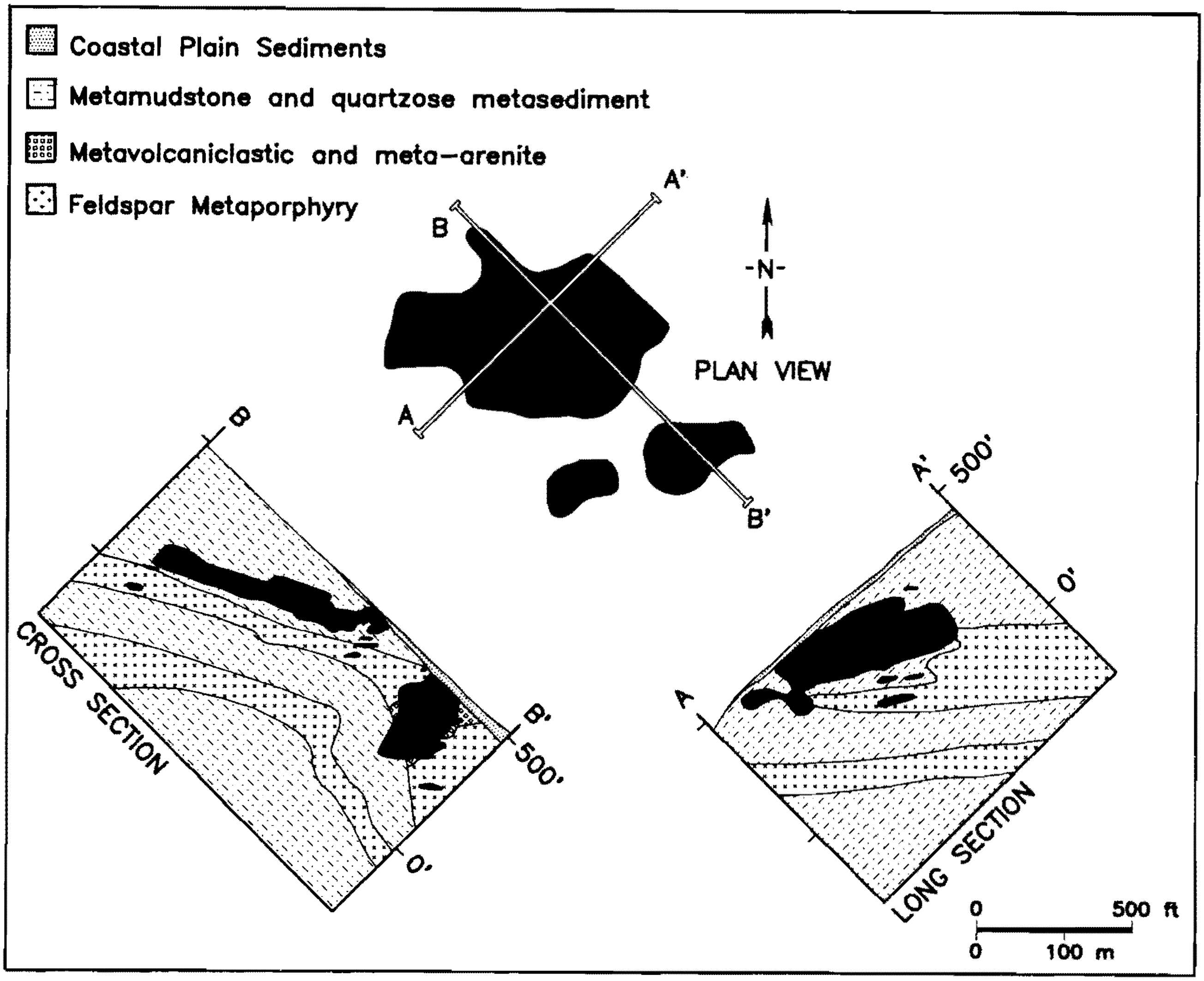

Figure 8. Plan and sectional views of the Red Hill and East Red Hill deposits showing the gold zones in dark shading.

the future, detailed relogging and pit mapping, emphasizing stratigraphic features, should add greatly to our understanding of the orebodies and may provide our most useful guide to ore.

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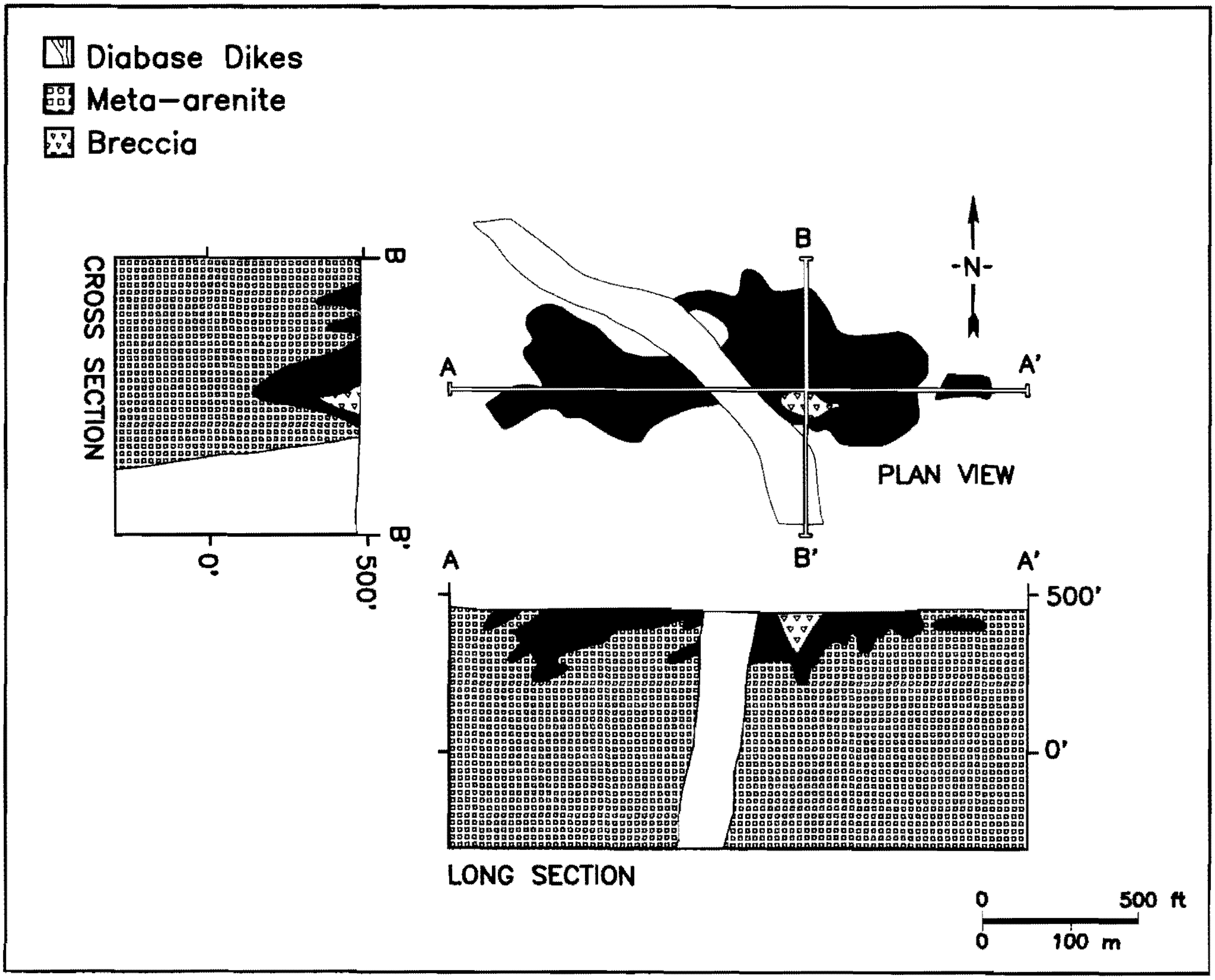

Figure 9. Plan and sectional views of the Champion and C-91 deposits showing the gold zones in dark shading.

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WHOLE ROCK AND TRACE ELEMENT GEOCHEMISTRY OF ROCKS FROM THE SNAKE DEPOSIT, HAILE GOLD MINE, LANCASTER COUNTY, SOUTH CAROLINA

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Abstract

Gold at the Haile mine occurs primarily in fine-grained quartzose metasediments of the Carolina slate belt. These rocks have been exposed to diagenesis, hydrothermal alteration, one or more episodes of regional metamorphism and extensive supergene weathering.

Multiple trace-element analysis of 96 samples from a single representative diamond drill hole (DDH 79) from the Snake gold deposit shows a positive correlation between Au, Ag, As, Sb, Te, Mo and Zn. The lack of significant base metals and the lack of elemental zoning is indicated. Analysis of whole-rock geochemistry of 30 samples at the Snake deposit shows that the gold-bearing rocks are indistinguishable from those devoid of significant gold.

Fire assay analysis of drill-hole samples from numerous deposits at the mine indicate that gold occurs within a narrow range of values. The highest value from 19,371 mineralized samples is only 4.653 ounces of gold per ton of rock. In addition, there is only a weak correlation between gold and molybdenum, although molybdenite is often visible in the ore.

Introduction

The Haile gold mine is located in north central South Carolina (Figure 1). The rocks at the mine consist of lower greenschist facies marine metasediments and metavolcanics of the Carolina slate belt. These rocks are divided into four lithologic units (Speer and Maddry, 1993):

Metamudstone—silt- and clay-sized sericite, chlorite and quartz phyllites, generally very thinly bedded.

Meta-arenite—metasediments that include quartzites, meta-arkoses, metawackes, metasiltstones and metacherts. These rocks are massive to bedded.

Feldspar metaporphry—metavolcanic rocks containing feldspar phenocrysts in an aphanitic groundmass. These rocks may be ash flow tuffs, lava flows or intrusives.

Metafragmental—pyroclastic or epiclastic rocks that contain prominent lithic fragments. These rocks also may include tectonic breccias that cannot be assigned to the rock types above.

Most gold occurs in the fine-grained rock types: metamudstones, metacherts and meta-arenites. Minor amounts of gold also are found in the feldspar metaporphyries and metafragmental rocks. The geochemistry and mineralogy of the ore reflect original protoliths.

Feiss (1982) suggests that slate belt rocks, including the Haile mine sequence, may have undergone an early period of diagenesis due to rock-sea water interaction. In addition, many researchers have reported suspected hydrothermal alteration (Spence and others, 1980; Bell, 1982; Kiff and Spence, 1988; Tomkinson, 1985; Hardy, 1987; and Hayward, 1989). Tomkinson (1985) and Hayward (1989) emphasized the role of metamorphism in the origin of the gold deposits. Speer and Maddry (1993) have pointed out the influence of protolith mineralogy and geochemistry, while Maddry and Speer (in press) have stressed the importance of supergene argillation and saprolitization.

Whole-rock geochemistry

Whole-rock geochemistry of a few samples from the Haile mine were first reported by Nitze and Wilkens (1897) and Sloan (1908). However, the first significant evaluation was completed by Tomkinson (1985) and included 52 pit-exposure and diamond drill core samples taken from many of the gold deposits. In addition, a suite of 30 diamond drill core samples from the Snake

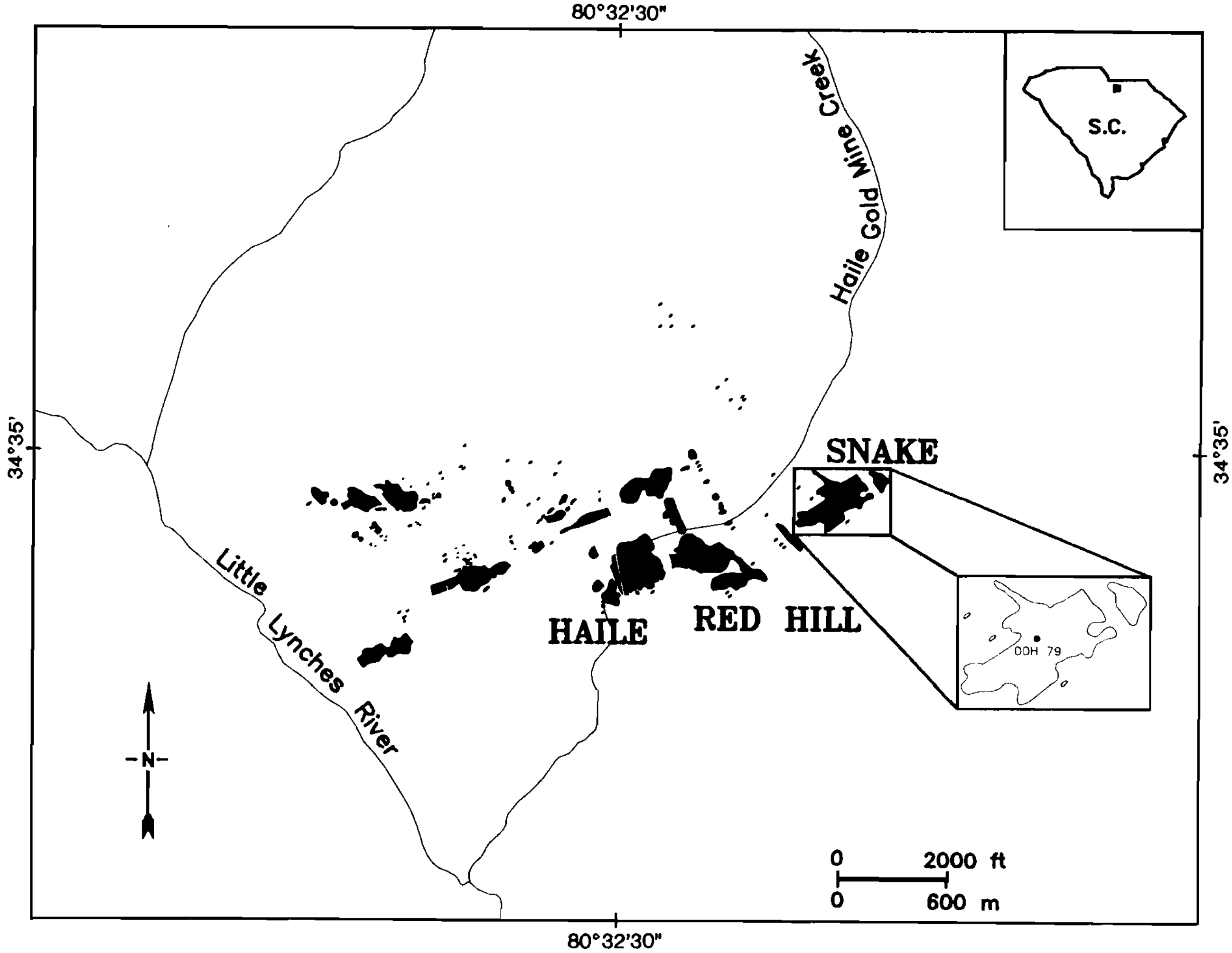

Figure 1. Location of gold deposits at the Haile gold mine.

deposit were analyzed in 1991 for Piedmont Mining Company, Inc. These analyses are similar to those of Tomkinson (1985).

The 30 Snake deposit samples, shown in Table 1, are grouped by rock type and are further divided into mineralized versus unmineralized. The bulk of the gold mineralization at the Snake deposit occurs in laminated metamudstone and fine-grained to cryptocrystalline masses of silica (quartzite and metachert) within the metamudstone. No widespread hydrothermal alteration appears to be present. Based on whole-rock geochemistry, gold-bearing rocks are indistinguishable from those devoid of significant gold. The high-silica rocks are lower in Al_2O_3, Fe_2O_3, MgO and MnO than surrounding rocks (Table 1). Fe_2O_3, however, varies considerably depending upon the abundance of pyrite.

The suspected high-mobility of Na_2O, K_2O, and CaO during diagenesis, hydrothermal alteration, metamorphism and supergene alteration renders the usual whole-rock classification models suspect. Tomkinson (1985) avoided this by using a classification scheme based on the immobile elements titanium, zirconium, yttrium and niobium. He found the rocks to be rhyodacite-dacite in composition. Phyllite (our metamudstone) is andesitic, but plots close to the dacite-rhyodacite field. The metamudstone at the Snake deposit is substantially lower in SiO_2 and higher in Al_2O_3, Fe_2O_3 and MgO than the other rock types (Table 1). Tomkinson (1985) suggests that the metamudstone may have had a different source than the other rock types.

The metafragmentals in the Snake deposit contain lithic clasts that are primarily porphyritic in texture; however, a small percentage of clasts are composed of metamudstone and meta-arenite. The porphyritic clasts are interpreted to have been derived from the feldspar metaporphyries. The meta-arenites are typically high in silica relative to metafragmentals and metamudstone and are locally feldspathic.

Trace-element geochemistry

Trace-element geochemistry was first used in gold exploration at the Haile mine by Cyprus Exploration Company from 1973 to 1975. Independent studies have been reported by Tomkinson (1985) and Al-Otaibi (1987). Following the discovery of the Snake deposit in 1988, trace element analysis of one representative diamond drill core hole (DDH 79) was completed by Piedmont Mining Company, Inc. (Figures 2 and 3, Table 2). This hole intersected a sequence of interbedded and possibly folded metamudstones, meta-arenites and metafragmental rocks. This hole also intersected three gold-bearing zones, the most significant of which averaged 0.165 ounces of gold per ton of rock (opt) over an interval of 220 feet (Figure 2). Bismuth, cadmium, gallium, selenium and mercury show erratic or less than-detection-limit values and are not plotted on Figure 3, although they are listed in Table 2. Figure 3 reveals a strong positive correlation between gold, silver, arsenic, antimony and tellurium. A weaker positive correlation with molybdenum and zinc also is evident. No significant base metal values are associated with gold.

The gold, silver, arsenic, antimony and tellurium anomalies show very sharp boundaries. There is no obvious halo of trace elements or visual rock alteration peripheral to the gold zones.

Gold

Gold at the Haile mine occurs within a narrow range of values. A review of 19,371 property-wide drill-hole samples, containing greater than 0.001 opt fire-assay gold values, shows that the highest value is only 4.653 opt. The average value is 0.0263. Only 22 percent of 4,308 samples are greater than the average value, while only 0.22 percent of 43 samples are greater than 0.50 opt. Histograms of the sample values are shown in Figure 4.

Molybdenum

Molybdenite is a common accessory mineral in the gold-bearing rocks. It was noted first at the mine in 1897, although it was misidentified as graphite (Nitze and Wilkens, 1897). It was identified correctly first by Graton (1906).

The chemical relationship between molybdenum and gold appears to be inconsistent, and may vary

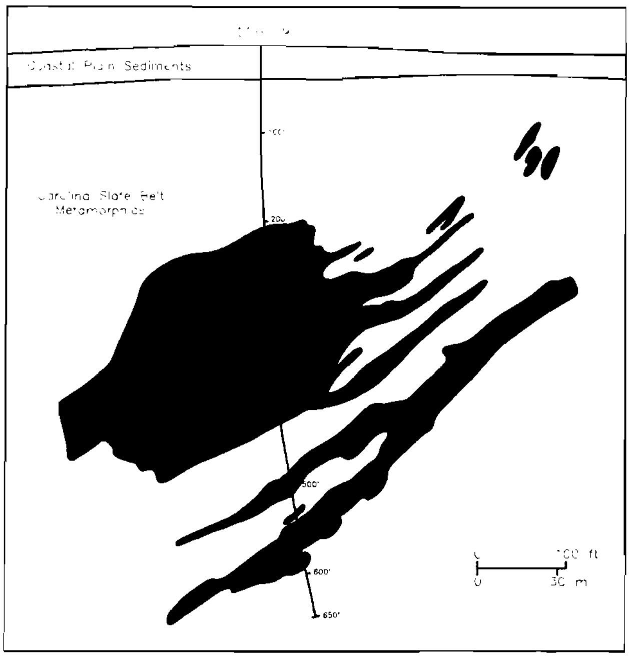

Figure 2. Cross section of DDH 79, Snake gold deposit. Gold greater than 0.01 opt is shown in dark shading. See Figure 1 for location of DDH 79.

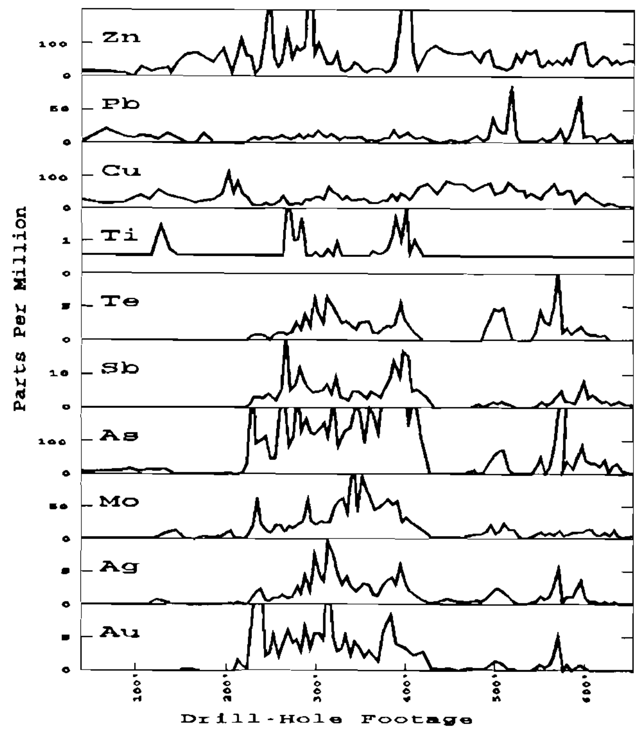

Figure 3. DDH 79 trace element graphs.

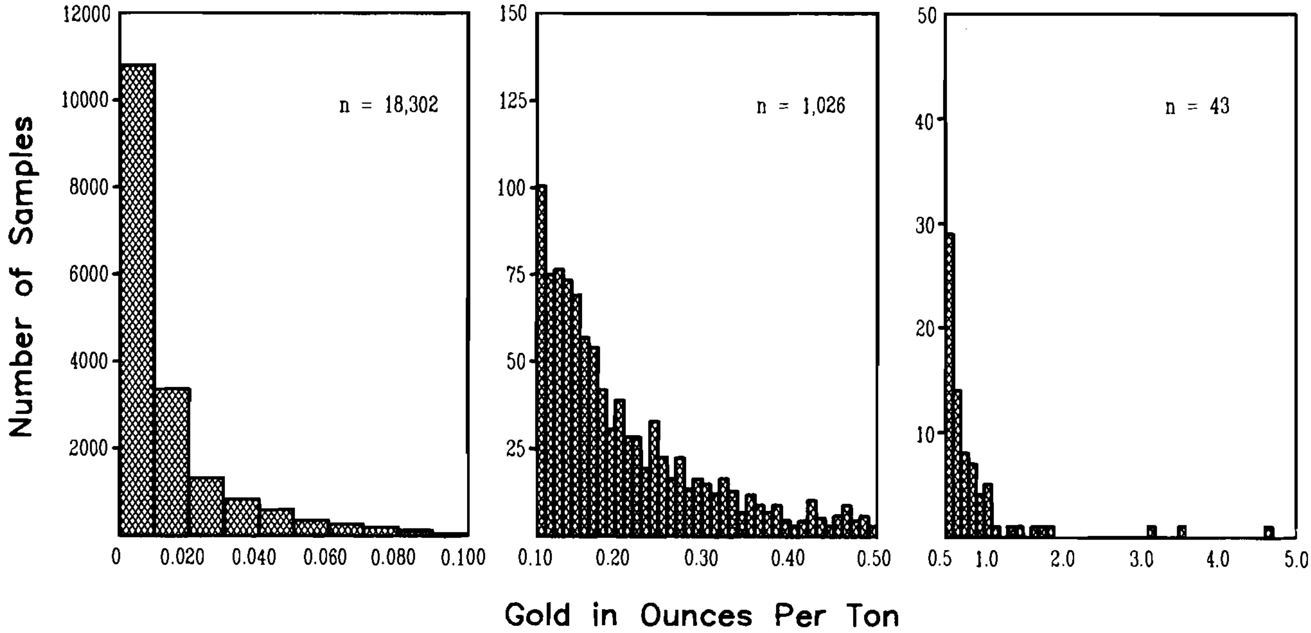

Figure 4. Histograms of gold values.

within individual deposits. A scatter plot of 96 gold and molybdenum values from DDH 79, in the Snake deposit, shows only a poor correlation coefficient of 0.4685 (Figure 5). A similar calculation for 851 drill-hole samples from six other deposits at the Haile mine shows a correlation coefficient of 0.4415. Al-Otaibi (1987) also reported a poor correlation between molybdenum for 32 rock-chip samples from the Haile and Bumalo deposits.

Conclusions

The rocks at the Snake deposit consist of predominantly thinly bedded metamudstone and other fine-grained metasediments. A sharp contact generally separates gold mineralized rocks from the surrounding host rocks; but, based upon whole-rock geochemistry, the gold-bearing rocks are essentially indistinguishable from the surrounding host rocks. Trace element geochemistry of one representative core hole reveals a strong positive correlation between gold, silver, arsenic, antimony and tellurium. A weaker positive correlation between gold, molybdenum and zinc also is indicated. The gold, silver, arsenic and tellurium show sharp boundaries with no obvious halo peripheral to the gold zones.

A review of 19,371 drill-hole samples from numerous deposits at the Haile mine indicate that the gold occurs within a narrow range of values. Only 22 percent of 4,308 samples are greater than the average value, while only 0.22 percent of 43 samples are greater than 0.50 opt.

Molybdenite is a common mineral at the Haile mine. However, a comparison of molybdenum with gold shows only a weak correlation.

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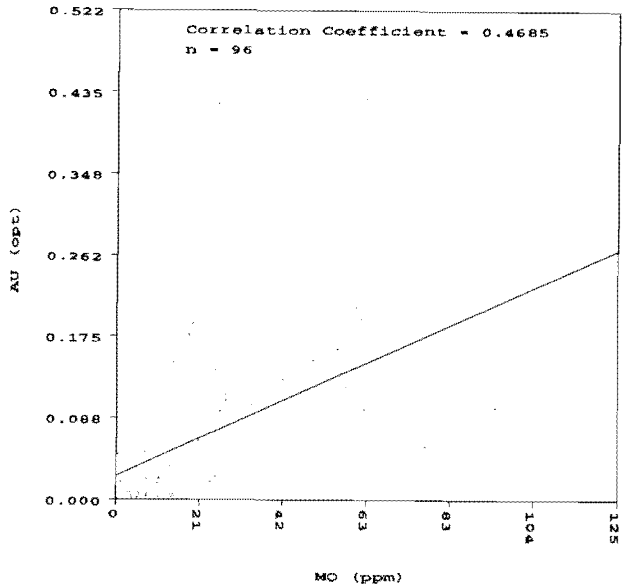

Figure 5. Scatter plot of gold and molybdenum values from DDH 79.

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Table 1. Whole rock geochemistry.

Sample #	1	2	3	4	5	6	7	8	9	10
Rk Type	Frag	Muds	Frag	Muds	Fmet	Fmet	Fmet	Gmuds	Gfrag	Fmet
SiO_2	69.43	61.54	73.11	63.61	68.18	75.60	66.62	67.31	66.68	74.34
TiO_2	0.42	0.77	0.46	0.85	0.36	0.21	0.31	0.67	0.52	0.22
Al_2O_3	14.66	15.63	15.36	17.76	18.23	12.58	13.47	16.04	20.28	13.86
$Fe_2O_3^*$	3.99	10.21	3.76	8.10	3.41	1.48	2.78	6.64	2.77	2.11
MnO	0.09	0.26	0.06	0.14	0.04	0.05	0.08	0.11	0.04	0.06
MgO	1.34	4.33	1.15	2.61	0.77	0.25	0.85	2.14	0.53	0.34
CaO	0.68	0.34	0.29	0.87	0.27	0.72	4.38	0.87	<0.01	1.15
Na_2O	2.77	0.27	2.56	0.69	3.13	1.71	3.00	0.24	0.24	3.54
K_2O	1.95	1.83	2.12	2.17	5.21	6.09	1.85	3.16	5.56	4.78
P_2O_5	0.12	0.27	0.15	0.16	0.02	0.10	0.10	0.14	nd	0.08
LOI	2.62	3.88	2.53	3.80	1.69	1.01	4.54	3.27	3.04	1.34
TOTAL %	98.07	99.33	101.55	100.74	101.31	99.80	97.98	100.59	99.66	101.82
Cr_2O_3	0.01	0.02	0.01	0.02	0.01	0.03	0.02	0.02	0.01	0.03
BaO	0.040	0.26	0.054	0.46	0.095	0.098	0.03	0.038	0.056	0.082
Se+	0.02	0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	0.02
Au+	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.21	0.80	<0.01

Sample #	11	12	13	14	15	16	17	18	19	20
Rk Type	Garen	Gfrag	Muds	Aren	Garen	Muds	Frag	Muds	Aren	Gfrag
SiO_2	90.18	83.96	66.40	71.27	68.23	60.42	57.42	65.27	70.23	77.72
TiO_2	0.16	0.15	0.78	0.35	0.41	0.91	0.54	0.80	0.39	0.22
Al_2O_3	5.34	8.43	17.53	16.34	20.14	17.86	19.28	17.87	14.76	10.13
$Fe_2O_3^*$	0.97	0.56	6.90	2.05	2.69	8.58	5.16	5.69	2.69	3.85
MnO	<0.01	0.05	0.14	0.08	0.07	0.18	0.15	0.12	0.12	0.08
MgO	0.01	0.11	2.51	1.14	1.47	2.37	1.80	2.00	0.81	2.00
CaO	<0.01	2.56	0.59	0.53	0.38	1.48	4.63	1.92	3.59	<0.01
Na_2O	0.08	0.16	0.44	0.38	0.47	0.31	4.40	0.36	0.83	0.16
K_2O	1.50	2.18	2.94	3.72	4.45	3.31	2.39	3.62	2.91	1.88
P_2O_5	nd	0.03	0.14	<0.01	0.44	0.24	0.22	0.13	0.15	nd
LOI	1.01	2.88	3.35	3.09	3.01	4.01	5.21	4.15	4.22	2.41
TOTAL%	99.35	101.06	101.72	98.95	101.76	99.68	101.19	101.95	100.69	98.45
Cr_2O_3	0.03	0.03	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
BaO	0.019	0.025	0.051	0.074	0.040	0.042	0.050	0.052	0.056	0.016
Se+	0.44	0.06	0.18	0.28	0.36	0.76	0.16	0.26	1.15	0.59
Au+	6.79	8.40	<0.04	<0.04	1.99	0.01	<0.04	<0.04	<0.04	2.16

Sample #	21	22	23	24	25	26	27	28	29	30
Rk Type	Aren	Muds	Fmet	Aren	Fmet	Fmet	Fmet	Gmuds	Gmuds	Aren
SiO_2	62.04	63.69	68.10	76.57	83.02	75.07	70.43	67.11	69.25	70.21
TiO_2	0.50	0.86	0.34	0.29	0.17	0.21	0.38	0.60	0.32	0.49
Al_2O_3	26.56	17.79	14.44	13.89	10.39	14.12	15.06	15.07	18.40	13.59
$Fe_2O_3^*$	1.91	7.60	2.92	2.00	1.48	2.12	3.44	8.96	4.36	3.71
MnO	0.02	0.14	0.07	0.07	0.02	0.05	0.12	0.09	0.01	0.19
MgO	0.42	2.45	0.84	0.66	0.23	0.41	0.81	2.46	0.55	0.97
CaO	<0.01	1.23	3.73	1.43	0.06	0.32	0.03	0.50	<0.01	3.41
Na_2O	0.93	0.31	3.35	0.18	4.28	5.18	4.46	0.13	0.32	0.20
K_2O	5.90	3.39	1.97	3.68	1.09	3.06	2.99	2.87	4.76	3.07
P_2O_5		0.11	0.06	0.05	<0.01	0.04	0.08	0.10	nd	0.10
LOI	3.54	3.47	3.91	2.74	0.64	0.62	1.46	3.39	3.96	4.26
TOTAL%	101.82	101.03	99.75	101.57	101.39	101.20	99.25	101.28	101.94	100.18
Cr_2O_3	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01
BaO	0.44	0.055	0.036	0.047	0.031	0.070	0.068	0.047	0.059	0.054
Se+	0.49	0.46	0.02	0.46	0.06	0.06	<0.02	0.84	2.60	0.18
Au+	0.06	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.17	8.91	<0.04

Table 1 (continued). Whole rock geochemistry.

Summary by rock type:

	Muds n=6	Gmuds n=3	Aren n=5	Garen n=2	Frag n=3	Gfrag n=3	Fmet n=8
SiO_2	63.48	67.89	70.06	79.21	66.65	76.12	72.57
TiO_2	0.83	0.53	0.40	0.29	0.47	0.30	0.27
Al_2O_3	17.41	16.50	17.03	12.74	16.43	12.95	14.02
Fe_2O_3*	7.85	6.65	2.47	1.83	4.30	2.39	2.47
MnO	0.16	0.07	0.10	0.04	0.10	0.06	0.06
MgO	2.71	1.71	0.80	0.79	1.43	0.89	0.56
CaO	1.07	0.45	1.79	0.19	1.87	0.85	1.32
Na_2O	0.40	0.23	0.50	0.28	3.24	0.19	3.58
K_2O	2.88	3.59	3.86	2.98	2.15	3.21	3.38
P_2O_5	0.18	0.12	0.08	0.44	0.16	0.03	0.06
LOI	3.78	3.54	3.57	2.01	3.45	2.78	1.90
Cr_2O_3							
BaO	0.045	0.048	0.055	0.030	0.048	0.032	0.063
Se+	0.28	1.15	0.51	0.40	0.01	0.04	<0.02
Au+	<0.03	3.10	<0.03	4.39	<0.03	3.79	<0.03

Rock type:

Muds → Metamudstone
Aren → Meta-arenite
Frag → Meta-fragmental
Fmet → Feldspar metaporphyry
G prefix indicates gold-bearing.

Element oxides are reported as weight percent.
* Total iron present has been recalculated as Fe_2O_3.
Au+ reported in ppm
Se+ reported as percent

nd - No data

Analysis by DC Plasma, extraction by Borate fusion, detection limit 0.01 PCT (BaO-0.001 PCT).
LOI by gravimetric, detection limit 0.05 PCT.

Table 2. DDH 79 trace element values in ppm.

Interval (Ft)	Au	Ag	Mo	As	Sb	Te	Tl	Cu	Pb	Zn	Bi	Cd	Ga	Se	Hg
40-50	<.048	.017	.904	3.43	<.242	<.484	<.484	23.2	4.12	8.93	<.242	<.097	<.484	<.967	<.097
60-70	<.047	.103	1.76	3.72	<.234	<.468	<.468	13.7	18.6	6.57	<.234	<.094	<.468	<.936	<.094
80-85	<.047	.029	1.55	7.20	<.236	<.473	<.473	15.5	6.09	7.93	<.236	<.095	<.473	<.945	<.095
90-95	<.049	.047	.994	11.30	<.246	<.492	<.492	25.2	4.20	<.984	<.246	<.098	<.492	<.984	<.098
100-105	<.049	.095	1.70	3.77	<.243	<.485	<.485	39.9	7.57	22.1	<.243	.293	<.485	<.971	<.097
110-115	<.048	.018	1.72	6.01	<.239	<.479	<.479	28.3	6.57	8.57	<.239	<.096	<.479	<.958	<.096
120-125	<.047	.923	2.14	6.16	<.235	<.47	1.40	54.6	3.30	13.7	<.235	.101	<.47	.94	<.094
130-135	<.047	.517	8.44	6.22	<.234	<.467	.652	39.9	13.6	18.5	<.234	.095	<.467	<.935	<.093
140-145	<.047	.032	12.1	1.78	<.233	<.466	<.466	10.7	4.76	37.5	<.233	<.093	1.72	<.931	.113
150-155	.336	.126	<.097	<.967	<.242	<.484	<.484	24.4	1.69	59.9	<.242	<.097	2.47	<.969	<.097
160-165	.215	.061	<.096	<.963	<.241	<.482	<.482	14.4	1.41	63.5	<.241	<.096	2.10	<.963	<.096
170-175	.088	.095	.362	<.952	<.238	<.476	<.476	21.1	11.6	50.3	<.238	<.095	1.52	<.952	<.095
180-185	.051	.056	.143	<.971	<.243	<.485	<.485	27.1	1.10	37.7	<.243	<.097	1.32	<.971	<.097
190-295	.052	.062	.270	<.973	<.243	<.486	<.486	46.1	1.61	88.6	<.243	<.097	3.47	<.973	<.097
200-205	<.05	.221	11.6	2.95	<.248	<.495	<.495	107.0	1.64	8.33	<.248	<.099	<.495	<.99	<.099
205-210	<.049	.071	2.06	<.975	<.244	<.487	<.487	45.3	.852	47.0	<.244	<.097	1.30	<.975	<.097
210-215	1.08	.441	.445	1.42	<.239	<.478	<.478	79.8	.839	106.0	<.239	<.096	3.04	<.956	<.096
215-220	.089	.211	1.30	3.70	<.239	<.479	<.479	47.7	1.26	57.9	<.239	<.096	1.56	<.958	<.096
220-225	.255	.156	5.83	33.7	.311	<.467	<.467	31.5	2.22	56.6	<.234	<.093	1.45	<.935	<.093
225-230	3.96	1.07	20.3	265.0	2.61	.560	<.478	7.11	5.49	4.11	.389	<.096	<.478	1.04	<.096
230-235	14.7	2.03	62.4	94.7	2.73	.835	<.481	6.59	3.47	19.3	.422	.145	<.481	1.08	<.096
235-240	17.9	2.45	22.2	105.0	2.64	.887	<.464	8.91	4.76	114.0	<.232	.895	<.464	1.19	<.093
240-245	2.28	.658	11.7	111.0	3.71	.690	.507	12.2	5.03	261.0	<.237	1.72	<.473	<.947	<.095
245-250	2.83	.634	8.27	50.1	2.70	<.484	<.484	9.77	3.52	54.3	<.242	.294	<.484	1.00	<.097
250-255	6.47	1.20	19.1	51.4	1.25	.655	<.479	10.3	4.70	25.5	<.239	<.096	<.479	1.49	<.096
255-260	2.20	1.23	20.6	186.0	4.58	1.00	<.466	19.8	7.84	38.9	<.233	.131	.703	.939	<.093
260-265	4.16	1.49	10.8	280.0	20.7	1.16	2.52	34.0	4.95	131.0	<.231	.629	<.461	1.18	<.092
265-270	6.08	1.15	18.2	85.9	4.74	.707	.909	9.87	3.72	48.7	<.247	.193	<.493	1.46	<.099
270-275	4.37	1.17	16.6	112.0	6.04	1.23	.935	8.92	5.10	82.6	<.232	.299	<.464	<.928	<.093
275-280	4.78	2.83	22.4	263.0	11.7	2.63	1.67	13.4	10.1	71.3	.257	.253	<.455	1.60	<.091
280-285	2.90	1.74	27.7	128.0	7.40	1.57	.515	9.01	5.08	85.1	<.241	.276	<.483	1.48	<.097
285-290	6.65	4.50	61.1	166.0	5.87	3.83	.488	24.0	9.38	372.0	.446	1.46	<.466	2.46	<.093
290-295	3.27	2.22	26.0	124.0	4.11	2.08	.662	21.8	7.51	62.8	<.242	.200	.507	1.37	<.097
295-300	5.56	7.50	22.5	118.0	4.39	6.23	<.46	32.3	16.9	94.4	<.23	.319	<.46	1.62	<.092
300-305	5.55	4.67	27.1	140.0	4.59	3.91	<.473	31.6	10.4	60.1	<.236	.260	<.473	2.30	<.095

Table 2 (continued). DDH 79 trace element values in ppm.

Interval (Ft)	Au	Ag	Mo	As	Sb	Te	Tl	Cu	Pb	Zn	Bi	Cd	Ga	Se	Hg
305-310	4.76	3.51	24.8	154.0	6.14	2.55	.718	23.0	7.01	35.4	<.238	.122	<.475	2.02	<.095
310-315	14.5	9.70	25.3	113.0	3.72	6.47	<.457	60.2	12.8	35.2	.245	.147	<.457	3.10	<.091
315-320	5.10	7.56	49.3	229.0	8.60	5.15	.938	46.0	8.23	65.4	.319	.230	<.473	1.87	<.095
320-325	2.89	4.97	57.1	84.9	2.74	3.98	<.471	40.8	3.83	14.6	.369	<.094	.656	1.17	<.094
325-330	3.34	3.25	62.0	112.0	2.31	2.51	<.479	23.1	7.29	11.6	.434	<.096	1.07	<.958	<.096
330-335	6.30	4.37	39.3	129.0	1.87	3.23	.485	37.0	5.78	21.3	.246	<.094	.827	1.11	<.094
335-340	2.39	2.81	125.0	137.0	4.88	2.73	.516	24.7	5.32	36.6	.727	.176	.544	1.01	<.098
340-345	4.43	2.09	41.8	213.0	4.86	1.53	.536	24.1	5.66	29.4	.315	.135	.640	3.03	<.094
345-350	3.39	2.81	94.7	183.0	3.41	2.45	<.482	28.2	5.17	12.4	.637	<.096	<.482	1.81	<.096
350-355	2.00	3.25	77.2	93.6	2.06	2.60	<.46	28.5	2.73	9.50	.540	<.092	.479	<.919	<.092
355-360	2.96	3.17	66.7	197.0	4.40	2.08	.604	16.8	4.25	17.8	.434	<.095	.599	1.42	<.095
360-365	2.21	1.53	44.9	182.0	3.50	1.07	.578	12.2	2.36	17.6	.352	<.096	.586	1.11	<.096
365-370	1.40	1.45	49.7	123.0	2.33	1.13	.586	13.2	3.72	17.9	.295	<.093	.488	.991	<.093
370-375	5.54	2.97	55.3	257.0	5.22	1.75	.700	20.0	5.36	8.66	.350	<.094	<.471	1.54	<.094
375-380	7.06	3.72	60.0	255.0	8.24	2.18	1.17	19.1	5.45	12.9	.387	<.097	<.483	1.70	<.097
380-385	8.36	4.20	53.9	308.0	13.2	2.01	1.65	41.7	18.5	40.1	.460	.102	<.466	2.51	<.093
385-390	4.14	2.95	57.4	306.0	8.67	2.44	.988	22.8	7.76	161.0	.470	.309	.521	1.89	<.094
390-395	3.66	6.00	27.6	795.0	16.1	5.45	1.76	43.1	10.0	365.0	.259	.511	.801	3.90	<.093
395-400	3.48	3.89	33.9	467.0	14.7	2.95	2.08	33.7	14.5	309.0	.294	.507	.089	3.98	.109
400-405	3.89	2.31	27.4	146.0	4.18	2.03	.601	24.5	8.43	67.0	<.244	.229	<.488	2.27	<.098
405-410	2.30	1.67	22.9	228.0	5.02	1.14	.967	12.4	4.57	14.0	<.242	<.097	<.484	2.05	<.097
410-420	2.77	.807	13.5	110.0	2.97	<.465	<.465	66.5	8.08	70.3	.349	.321	1.49	1.49	<.093
420-430	.293	.151	3.09	1.03	<.237	<.474	<.474	71.9	2.12	89.4	<.237	<.095	5.01	<.949	<.095
430-440	.156	.196	3.82	4.02	<.24	<.48	<.48	41.8	1.95	71.3	<.24	<.096	5.50	<.96	<.096
440-450	.324	.721	3.55	18.4	<.25	<.499	<.499	81.5	4.62	64.7	.258	.133	5.07	<.998	<.1
450-460	<.047	.404	2.48	5.15	<.236	<.473	<.473	70.7	2.29	66.4	<.236	.139	5.18	<.945	<.095
460-470	.310	.234	5.46	4.21	<.23	<.46	<.46	71.7	3.18	71.2	<.23	.096	4.71	<.921	<.092
470-480	.156	.405	7.64	11.9	.383	<.473	<.473	52.9	9.69	39.5	.366	<.095	2.41	<.947	<.095
480-482	.139	.248	7.65	2.36	<.241	<.483	<.483	59.2	2.75	58.8	<.241	<.097	3.37	<.965	<.097
482-490	.198	.786	13.5	9.04	.329	1.64	<.474	72.8	6.17	67.4	.478	<.095	3.61	<.949	<.095
490-495	.693	1.63	23.5	47.7	1.25	3.36	<.479	73.6	36.2	26.3	.535	.129	1.66	1.33	<.096
495-500	1.41	2.35	9.34	60.5	1.29	4.78	<.475	39.9	21.3	26.1	<.238	.097	.995	<.951	<.095
500-505	1.23	2.44	13.4	71.0	1.47	4.30	<.46	33.6	14.9	19.8	<.23	.141	.695	<.919	<.092
505-510	.843	1.72	24.8	75.9	1.10	4.78	<.488	39.3	15.4	14.1	<.244	.125	.617	1.58	<.098
510-515	.174	1.10	14.6	14.7	.520	2.15	<.481	86.2	84.2	22.7	1.19	.191	1.15	1.49	<.096

Table 2 (continued). DDH 79 trace element values in ppm.

Interval (Ft)	Au	Ag	Mo	As	Sb	Te	Tl	Cu	Pb	Zn	Bi	Cd	Ga	Se	Hg
515-520	.061	.438	14.5	1.95	<.241	<.483	<.483	64.1	12.2	63.1	.319	<.097	3.32	<.965	<.097
520-525	<.048	.146	6.67	<.967	<.242	<.484	<.484	51.1	3.03	40.5	<.242	<.097	1.96	<.969	<.097
525-530	<.048	.085	2.49	1.05	<.242	<.484	<.484	51.2	3.19	70.8	<.242	<.097	3.76	<.967	<.097
530-535	<.05	.093	1.58	<.99	<.248	<.495	<.495	31.9	2.40	64.7	<.248	<.099	3.06	<.99	<.099
535-540	.086	.222	3.98	<.978	.248	<.489	<.489	46.1	3.90	74.6	<.245	<.098	3.57	<.978	<.098
540-545	.248	.397	7.76	24.6	.712	1.17	<.479	35.1	3.94	30.5	<.239	<.096	1.45	<.958	<.096
545-550	.783	1.25	10.8	57.4	1.39	4.17	<.471	26.7	7.61	27.0	.273	.400	<.471	1.24	<.094
550-555	.410	.616	7.26	1.72	.699	2.63	<.471	42.9	4.29	47.5	<.235	.099	<.471	<.942	<.094
555-560	.812	1.12	10.6	20.6	1.24	2.36	<.408	52.2	4.10	32.6	<.234	<.094	.704	1.06	<.094
560-565	1.76	2.46	7.31	97.6	2.96	5.20	<.469	72.8	8.08	48.7	<.235	<.094	1.46	1.40	<.094
565-570	5.03	5.43	14.4	220.0	4.88	10.5	<.498	46.6	20.6	33.3	.700	<.1	.803	1.88	<.1
570-575	.105	.155	5.28	10.7	1.87	.979	<.492	44.6	2.08	52.8	<.246	<.098	1.81	<.984	<.098
575-582	.795	.899	7.72	40.9	1.67	1.70	<.492	51.8	10.7	37.2	.322	<.098	1.07	<.984	<.098
582-590	.129	.921	10.6	16.8	1.08	.696	<.482	52.3	29.6	92.2	.252	.820	<.482	<.963	<.096
590-595	.630	3.52	10.4	90.4	6.41	1.99	<.477	16.4	72.1	98.7	<.239	.925	<.477	<.954	<.095
595-600	.251	.961	14.3	45.0	2.36	1.04	<.461	32.1	8.08	35.2	<.231	.160	<.461	<.923	<.092
600-605	.120	.314	14.0	34.1	3.52	.853	<.473	47.1	9.80	29.9	<.237	<.095	<.473	<.947	<.095
605-610	.174	.339	6.89	35.2	2.84	.829	<.456	34.9	11.2	45.8	<.228	<.091	.627	<.912	<.091
610-615	.071	.155	7.45	25.6	1.21	.546	<.465	26.1	4.53	60.0	<.232	<.093	.739	<.929	<.093
615-620	.085	.300	10.7	45.8	1.75	.598	<.459	17.8	8.33	54.8	<.229	.146	<.459	<.917	<.092
620-625	<.048	.111	7.86	9.35	.715	<.481	<.481	5.57	2.93	33.6	<.24	.245	<.481	<.962	<.096
625-630	<.047	.207	14.7	27.7	.980	<.47	<.47	9.23	4.69	46.0	.287	.205	<.47	<.94	<.094
630-635	.071	.136	6.33	35.6	1.48	<.479	<.479	6.10	4.53	35.3	.276	<.096	<.479	<.958	<.096
635-640	.05	.098	3.46	14.5	.713	<.498	<.498	3.36	4.66	43.5	<.249	<.1	<.498	<.996	<.1
640-645	<.049	.08	4.70	10.4	.686	<.492	<.492	6.91	6.44	47.1	<.246	<.098	.595	<.984	<.098
645-650	<.05	.073	5.18	8.83	.521	<.495	<.495	3.72	3.47	47.5	<.248	<.099	.575	<.99	<.099
Detection Limits	0.05	0.015	0.01	1.0	0.25	0.50	0.50	0.025	0.25	1.0	0.25	0.25	0.50	1.0	0.10

Analysis by ICP Graphite Furnace AA, 5 gm standard digest.

South Carolina Geology (1993 for 1992), V. 35, p. 37-54.

GEOCHEMICAL SIGNATURE OF ALTERATION AT THE BREWER GOLD MINE, JEFFERSON, SOUTH CAROLINA

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Abstract

Hydrothermal gold mineralization in the Brewer area is hosted by Late Precambrian to Cambrian metavolcanic rocks of the Persimmon Fork Formation of the Carolina slate belt. Geochemical analysis of these volcanic tuffs, flows and breccias indicates a rhyolitic composition (SiO_2, 70-80%; Al_2O_3, 11-19%; Fe_2O_3, 2.0-4.1%; Na_2O, 0.1-5.1%; K_2O, 2.1-3.9%) within a tholeiitic suite (alkalies 3.0-7.0%). Metasedimentary rocks, stratigraphically overlying the metavolcanic rocks, have a different composition (SiO_2, 52-56%; Al_2O_3, 17-26%; Fe_2O_3, 5.7-12.3%; Na_2O, 0.1-1.7%; K_2O, 1.3-6.0%).

The gold mineralization is accompanied by hydrothermal alteration in the Brewer area. Mineral assemblages indicate the following alteration pattern in the area: a silicic center (quartz-pyrite breccia); an advanced argillic inner zone (quartz-andalusite-alunite rock); a sericitic outer zone (quartz-sericite rock); and a patchy propylitic outermost zone (chlorite-epidote-quartz rock) grading into unaltered metavolcanic rocks. Geochemical analysis of the unaltered and hydrothermally altered rocks reveals variations in element concentrations among alteration zones and a crude chemical zonation. Hydrothermally altered rocks are generally enriched in Si, Cu, Mo, Pb, Zn and S and depleted in K, Mg and Rb relative to host volcanic rocks. Si, Fe, Zn, Pb, Cu and S are generally enriched toward the center of the alteration halo; whereas, K, Na, Mg and Ba are depleted. Al and Ti appear to have behaved as immobile elements. Some small breccia pipes in thesouthern part of the sericitic zone have compositions similar to the Brewer breccia rocks, implying that they might have formed as part of the same system as the main silicic central zone. Although Al_2O_3 is quite high in some andalusite-rich samples, the Al_2O_3 content in rocks from the advanced argillic zone is quite similar to rocks from other altered zones and the host metavolcanic rocks (10-20% Al_2O_3). Despite some differences, the tectonic setting, alteration pattern and alteration types in the Brewer mine area suggest that it is an epithermal acid-sulfate type deposit. The lower greenschist facies metamorphism in the region during the Taconic orogeny does not seem to have significantly affected the chemistry of the Brewer rocks and the hydrothermal alteration pattern.

Introduction

Volcanic-hosted epithermal precious-metal deposits have been studied extensively because of their economic significance and their analogy to active hydrothermal systems (Hayba and others, 1985; Heald and others, 1987; Henley, 1985; Field and Fifarek, 1985; Bodnar and others, 1985). However, most of these studies have been conducted primarily in unmetamorphosed and young (Tertiary) volcanic terranes (Buchanan, 1981; Hayba and others, 1985; Silberman and Berger, 1985; Heald and others, 1987; Berger and Henley, 1988). There is little information on the older volcanic-hosted epithermal deposits, which may have been affected by later regional metamorphism and igneous activity. The deposits in metamorphic terranes may differ from those in unmetamorphosed terranes, especially in terms of mineral assemblages (Ririe, 1990a).

The Carolina slate belt is one of the most interesting and metallogenically significant terranes of the eastern United States, as it hosts many different types of metallic and nonmetallic mineral deposits (Feiss, 1982, 1985; Feiss and others, 1991). Despite low-grade regional metamorphism and Paleozoic igneous activity, the Carolina slate belt, comprised largely of Precambrian to late Paleozoic volcanic and volcaniclastic rocks, has preserved a large number of epigenetic precious-metal deposits of subvolcanic origin, including the Brewer deposit. Worthington and Kiff (1970) suggested that these deposits are similar to the epithermal precious metal deposits which occur in

Tertiary volcanic rocks of the western United States. Feiss (1982) summarized the geochemistry of the volcanic rocks of the Carolina slate belt and suggested that they represent a calc-alkaline to tholeiitic bimodal suite emplaced in a subduction-related environment.

Gold mineralization in the Brewer area occurs in an intense silica-aluminosilicate alteration complex that is developed within Precambrian to Cambrian metavolcanic rocks (Persimmon Fork Formation) of the Carolina slate belt (Butler, 1985; Butler and others, 1988; Nystrom, 1972; Schmidt,. 1985). The Brewer deposit, mined intermittently over the last hundred years (Butler, 1988), currently is operated by the Brewer Gold Co. Earlier studies in the Brewer mine area (Graton, 1906; Pardee and Park, 1948; Cherrywell and Butler, 1984; Butler, 1985; Schmidt, 1978, 1985; and Butler and others, 1988) focused mainly on reconnaissance mapping and field description. Jaacks (1986) conducted a geochemical survey of the ore zones and recently, Scheetz (1991) has provided a detailed account of the hydrothermal alteration in the area.

The purpose of this paper is to provide detailed information on the geochemical signatures of the Brewer deposit and its alteration zones and present a comparison of this metamorphosed deposit with epithermal acid-sulfate type deposits in unmetamorphosed terranes.

Local geology

The Brewer gold mine is in Chesterfield County, South Carolina, 1.5 miles southwest of Jefferson. The mine lies on a topographic high that is bounded by the Lynches River to the west and its tributary, Little Fork Creek to the east. The deposit occurs in the Carolina slate belt, a northeast-southwest trending metamorphic terrane of the Piedmont province in the southern Appalachians (Figure 1). The Carolina slate belt consists of volcanic and sedimentary rocks of late Proterozoic to Cambrian age that have been metamorphosed to lower greenschist facies and intruded by various plutons (Butler and Secor, 1991; Butler, 1985; Conley and Bain, 1965). Metavolcanic rocks include volcanogenic clast-dominated pyroclastics, epiclastics and lava flows ranging up to 13 km in stratigraphic thickness. Metasedimentary rocks are dominated by mudstone, siltstone and graywacke.

In northern South Carolina, the Carolina slate belt consists of a predominantly felsic metavolcanic sequence, the Persimmon Fork Formation, that is overlain by metasedimentary rocks of the Richtex Formation (Secor, 1986, 1988). This belt is intruded by Paleozoic granitic bodies, such as the Pageland, Liberty Hill and Lilesville plutons (Figure 2). The geology of the Jefferson quadrangle, which includes the Brewer mine area, has been described by Minard (1971) and Nystrom (1972). Metavolcanic rocks, considered equivalent to the Persimmon Fork Formation (Nystrom, 1972), consist of an interbedded mafic-felsic volcanic unit and a felsic volcanic unit. The metasedimentary rocks, mostly laminated slates, are correlated to the Richtex Formation. The "Pageland granite", a quartz monzonite pluton, is exposed northwest of the Brewer gold mine. Coastal Plain sediments overlap onto the Brewer area.

Metavolcanic rocks in the Brewer area include volcanic tuffs, flows and breccias. Petrographic studies reveal that most of the pyroclastic rocks are felsic in composition. Volcanic tuffs include rhyolitic crystal and lithic tuffs. Crystal tuffs are composed of quartz, K-feldspar and plagioclase crystals in a matrix of fine-grained quartz, sericite and pumice fragments. Lithic tuffs consist of fragments of various types of volcanic rocks within a fine-grained matrix. Some of the tuffs contain both crystals and lithic fragments, and most show sorting and well-preserved stratification. Volcanic flows are not well stratified and contain blocks, lapilli and ash with some individual blocks over 10 cm in diameter. Lapilli consist of both lithic fragments and crystals of quartz and feldspar. The matrix is composed of fine-grained quartz, sericite, iron-oxide and silica.

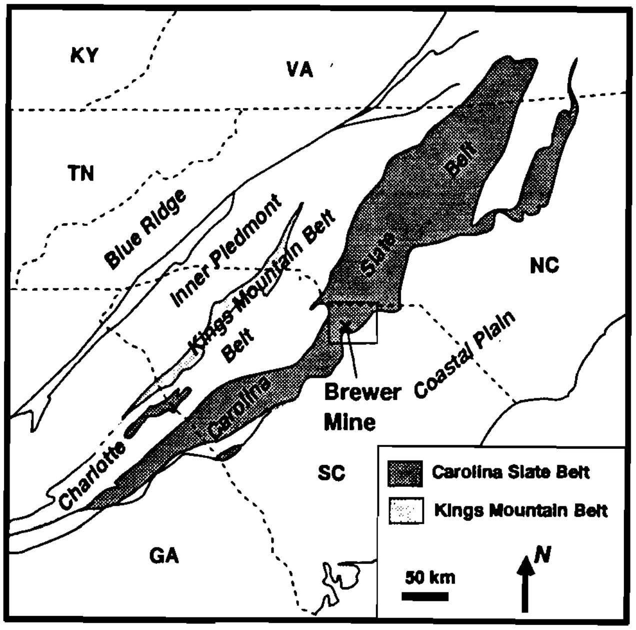


Figure 1. General geologic map of the southern Appalachian Piedmont, showing the location of the Brewer mine in the Carolina slate belt (after Butler, 1985).

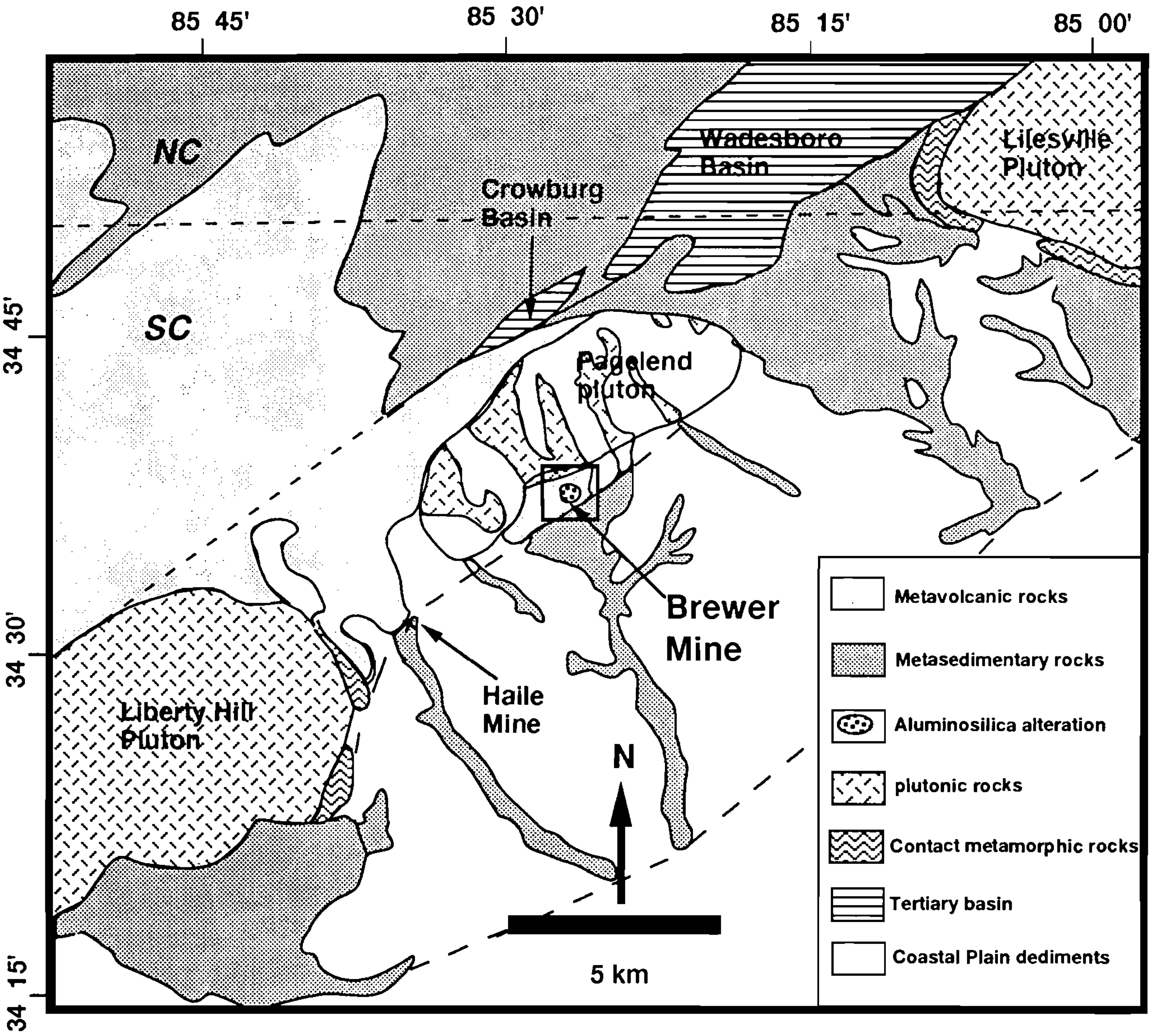


Figure 2. Generalized geologic map of the Brewer area (after Bell and Popenoe, 1976; Butler and others, 1988; Scheetz, 1991).

Volcanic breccias contain angular lithic fragments (typically with composition similar to that of the matrix) and a matrix of quartz, sericite and iron-oxides. The volcanic flows and breccias suggest the presence of a volcanic center near the Brewer area.

Metasedimentary rocks in the Brewer area include mudstone, siltstone and argillite. The mudstone and siltstone are typically well laminated and, close to the Brewer mine, are interlayered with volcanoclastics. Due to compositional and size differences, the interbedded rocks show distinct color layering in outcrop. Mudstones consist of fine-grained quartz, sericite and clays. Argillite, a product of regionally metamorphosed mudstone, has a mineral assemblage characterized by biotite, epidote, chlorite, quartz and hematite.

The volcanic and sedimentary rocks have been metamorphosed during a later regional metamorphic event, probably the Taconic orogeny. The metamorphic grade, based on the mineral assemblages present in the slate, is inferred to be lower-greenschist facies, as suggested earlier by Butler (1985). This is consistent with the overall metamorphic grade of the Carolina slate belt (Butler, 1991). Despite the metamorphism, many of the primary textures in the volcanic and sedimentary rocks, such as bedding planes and orientation of crystals and lithic fragments, are well preserved.

Gold mineralization

The Brewer mine occurs within the felsic volcanic rocks of the Carolina slate belt close to and partly under a thin edge of overlapping Coastal Plain sediments. Gold mineralization occurs in an intensely silicified zone composed of brecciated quartz-sulfide rocks, quartz-andalusite breccias and massive sulfide-quartz rocks. Two ore bodies have been delineated: the main ore body of the Brewer pit, and a smaller body (B-6) which is located to the southeast of the main ore body (Figure 3). The main ore body in the Brewer pit comprises quartz-pyrite breccias, quartz-andalusite breccias and quartz-topaz rocks. The breccias are multiphase, heterolithic, matrix- or clast-supported breccias (Scheetz and others, 1991). Most clasts within the breccias consist of pre-existing breccia fragments. Fine-grained quartz, various sulfide minerals and topaz compose the breccia matrix. The B-6 ore body is tabular, extending along a northwestwest-southeasteast direction, perhaps along a fault zone. The western part of the ore body is composed of intensely fractured breccia and quartz-andalusite rock and occurs along the contact of the two lithologies. The eastern part of the ore body was originally a massive sulfide rock containing some quartz, andalusite, kyanite and topaz, but now mainly is represented as an aluminosilicate-bearing gossan.

Although quartz and pyrite are the dominant minerals in the mineralized zones, aluminosilicate minerals, such as andalusite and paragenetically later kyanite, may be locally abundant. Topaz occurs either in veins or as fine-grained matrix in the breccias. Enargite also is quite abundant in some quartz-sulfide breccias. Accessory minerals include sphalerite, chalcopyrite, bornite, cassiterite, chalcocite, tetrahedrite, galena, ilmenite, cinnabar and native sulphur (Butler and others, 1988; Scheetz, 1991). Gold primarily occurs along grain boundaries.

Hydrothermal alteration

The gold-bearing silicic zone at the Brewer is part of a much larger hydrothermal alteration system that extends more than two kilometers across and has a near-circular shape in plan view (Figure 3). Despite subsequent regional metamorphism, the hydrothermal alteration zones are easily discernible by their mineral assemblages, especially in the inner part of the system where mining has occurred. The alteration has been described in the literature as "widespread silicification and extensive development of pyrophyllite and sericite" (Pardee and Park, 1948), "massive quartzite" (Nystrom, 1972), "quartz granofels of high-fluorine subvolcanic alteration" (Schmidt, 1985) and, most recently, "quartz-sulfide inner zone and quartz-sericite phyllite outer zone" (Scheetz and others, 1991).

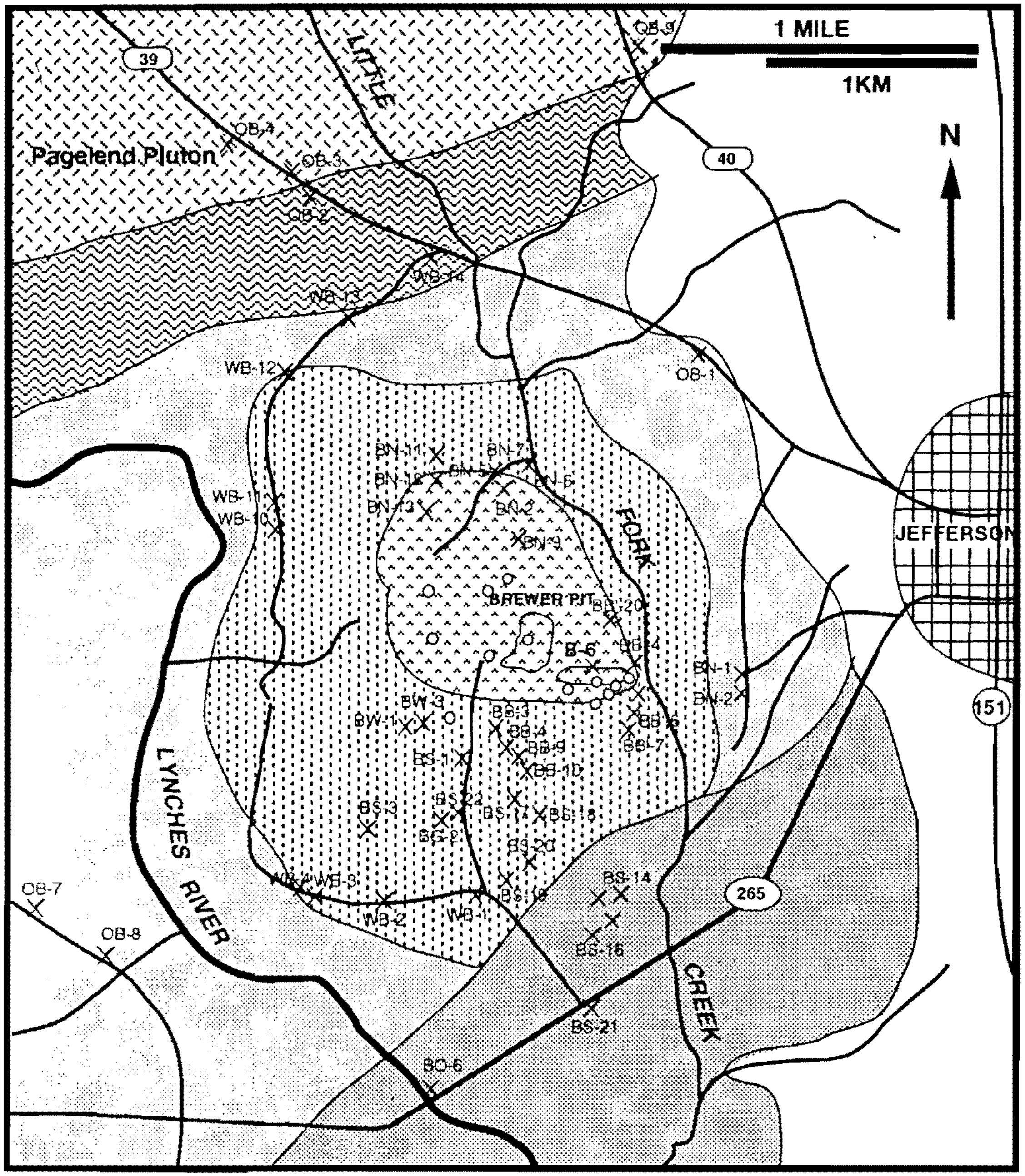
Based on petrographic characterization and classifications summarized by Heald and others (1987), four types of hydrothermal alteration can be recognized in the Brewer area: (a) silicic, (b) advanced argillic, (c) sericitic and (d) propylitic.

Silicic alteration

Silicic alteration in the Brewer mine area is represented by quartz-sulfide rocks and is confined to the central part of the alteration system. Geochemically, it is characterized by an extreme abundance of silica, a hydrothermally introduced component. Quartz and pyrite are the dominant minerals with quartz often constituting more than 80 percent of the rock. Quartz and pyrite occur in the clasts and matrix. Pyrite commonly occurs in the matrix of matrix-supported breccia and in the fractures of clast-supported breccia, behaving as a cementing material. Quartz and pyrite are fine-gralned; whereas, the clasts are typically fine-grained aggregates of quartz and minor pyrite. Locally, topaz occurs in the matrix. Andalusite is present locally, especially in the B-6 area, where it can be quite abundant along with quartz and pyrite. Enargite is concentrated in some breccias. As discussed above, many accessory sulfide minerals are present in this zone. Pyrophyllite occurs along the fractures locally, typically associated with quartz veins. Gold mineralization is confined mainly to the silicic zone.

Advanced argillic alteration

Advanced argillic alteration is characterized by the assemblage quartz, alunite and andalusite, with varying amounts of sericite, pyrophyllite, pyrite, topaz, diaspore, lazulite and kaolinite. The rocks are typically quartz-andalusite rocks with local breccia textures. Andalusite occurs as porphyroblasts in a fine-grained quartz-sericite matrix and as smaller grains within fractures. It is usually anhedral and, in some cases, partially replaced by kyanite, quartz and pyrophyllite. Alunite is present in three forms: microcrystalline aggregates, disseminations in the matrix and vein-fillings. In microcrystalline aggregates, alunite and quartz ap-



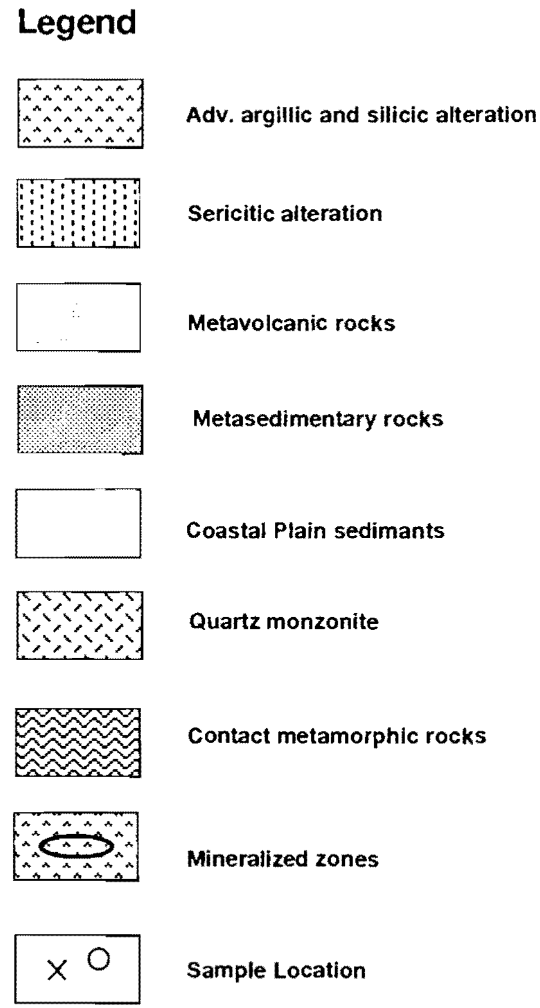


Figure 3. Geologic map of the Brewer mine, showing the distribution of hydrothermal alteration (after Nystrom, 1972; Schmidt, 1985; Scheetz, 1991). Note the concentric pattern of the silicic, advanced argillic and sericitic alteration zones.

parently replaced phenocrysts in the original volcanic rocks, most likely feldspars. As disseminations in quartz-dominated matrix, alunite is fine-grained, tabular to columnar, and randomly oriented. Alunite, with quartz and andalusite, also occurs in veins. Quartz typically occurs as fine-grained, anhedral crystals that constitute the matrix, although some appear as aggregates. Kyanite occurs in the alteration zone, but only as replacement of andalusite, so it is probably a product of regional metamorphism.

Sericitic alteration

Sericitic alteration is represented by the assemblage quartz and sericite, with some pyrite and minor ilmenite. The rocks commonly are metamorphosed to quartz-sericite schist and phyllite, but original volcanic textures, such as pyroclastic and flow textures, are preserved locally. The schist typically is comprised of fine-grained quartz-rich or sericite-rich, or both, compositional layers. Quartz aggregates are common along foliation. Iron-oxide stains mark foliation along pyrite-rich layers that parallel foliation. Sericite is oriented along foliation planes, but the foliation penetrates sericite aggregates (Scheetz, 1991) indicating that the sericite is pre-tectonic. Chloritoid, occurring as porphyroblasts in the quartz-sericite schist, exhibits syntectonic growth within the foliation, indicating a regional metamorphic origin.

A few breccia pipes were identified in the southern part of the sericitic zone. These breccia pipe rocks have an assemblage of quartz, andalusite, pyrophyllite, sericite and iron-oxide, and they exhibit brecciated textures. The rocks are similar to brecciated andalusite-quartz rocks in the advanced argillic alteration zone.

Propylitic alteration

A mineral assemblage of quartz, epidote, calcite, chlorite and pyrite defines the propylitic alteration. Sericite, K-feldspar, hematite, rutile and ilmenite are present in minor amounts. The rocks exhibit volcanic pyroclastic textures (breccia and flow), similar to those observed in the volcanic country rocks not affected by hydrothermal alterations. Calcite occurs as replacement of plagioclase phenocrysts and as fine-grained aggregates in the matrix. Epidote is present as elongated crystals or as radiating aggregates. Chlorite constitutes only a minor component in the rocks.

Silicic alteration forms the core of the hydrothermal system and is surrounded by a zone of advanced argillic alteration. These two zones broadly correspond to the "massive quartzite zone" of Nystrom (1972) and the "quartz granofels zone" of Schmidt (1985). They probably represent the center of a volcanic system - a cinder zone, a caldera or a diatreme (Nystrom, 1972). Sericitic alteration surrounds the zone of advanced argillic alteration and grades outward to either propylitic alteration or unaltered volcanic rocks. The sericitic zone is described by Nystrom (1972) as sericite phyllite and by Schmidt (1985) as quartz-sericite-pyrite schist. Propylitic alteration occurs sporadically outside of the sericitic zone, mainly in the southern and southwestern parts of the system. The alteration zoning pattern is similar to that of epithermal acid-sulfate deposits and its crude concentric pattern suggests a pre-metamorphic hydrothermal origin.

Geochemistry of the alteration zones: analytical procedure

About 90 samples from the Brewer mine area have been analyzed for major and trace elements in order to determine geochemical signatures of the alteration zones and possible geochemical associations. The samples are mainly from various alteration zones and unaltered volcanic rocks. A few samples of metasedimentary rocks, plutonic rocks and contact metamorphic rocks also were analyzed. Analyses were performed on pressed pellets (briquettes) of finely ground powder by an in-house EG&G ORTEC Energy-dispersive X-ray Fluorescence Spectrometer (Johnson and King, 1987). The calibration protocol for XRF analysis was prepared using standard reference materials (Abbey, 1983) available from the U.S. Geological Survey, the National Bureau of Standards, Canada Certified Reference Materials Projects and other institutes. The LOI (loss on ignition) was determined gravimetrically and includes the loss of volatile substances, such as H_2O and CO_2, as well as any weight gain from stoichiometric oxygen through the oxidation of Fe^{2+} to Fe^{3+}.

All the major elements (Si, Al, Na, Mg, Ca, Fe, Ti, Mn, P) are reported as oxide in percent and trace elements (Cu, Zn, Pb, Mo, Ni, Cr, Co, V, Rb, Sr, Y, Zr, Nb, Ba) in parts per million (ppm). Table 1 lists the average major and trace element compositions for the various rock types in the Brewer mine area, as well as adjacent plutonic and contact metamorphic rocks.

Unaltered metavolcanic and metasedimentary rocks

An important task in the geochemical characterization of alteration zones is determination of the protolith. The apparently unaltered metavolcanic rocks chosen

Table 1. Major and trace element composition of various rocks in the Brewer area.

	Metasedimentary rocks	Metavolcanic rocks	Sericitic	Advanced argillic	Silicic	Breccia pipes	Hornfels	Pageland granite
No. of Analyses	4	7	17	21	9	3	3	3
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Na_2O	0.54	1.42	0.77	1.07	0.63	0.60	3.05	3.96
K_2O	3.25	3.03	2.21	1.05	0.32	0.05	1.42	4.51
Al_2O_3	21.8	14.6	12.6	14.5	13.7	16.7	15.8	13.2
TiO_2	0.94	0.36	0.43	0.36	0.34	0.42	0.59	0.17
SiO_2	56.6	73.7	77.3	74.5	78.5	75.9	60.4	74.1
MgO	2.07	0.45	0.17	0.33	0.17	0.09	3.51	0.38
CaO	1.11	0.06	0.05	0.01	0.00	0.00	5.31	1.02
Fe_2O_3	8.36	2.79	3.09	1.97	1.71	3.10	6.42	1.78
MnO	0.06	0.03	0.03	0.02	0.02	0.03	0.12	0.02
P_2O_5	0.13	0.06	0.16	0.40	0.29	0.10	0.07	0.10
LOI	5.46	2.87	2.61	6.31	4.22	3.10	2.16	0.93
Total	100.8	99.6	99.6	101.5	100.3	100.2	99.2	100.3
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Cu	38	17	19	21	22	15	37	18
V	*419	109	*204	114	98	154	53	0
Cr	30	4	4	9	6	7	65	6
Co	39	5	6	7	6	6	15	4
Ni	50	7	6	6	9	7	34	7
Zn	*203	52	64	*217	116	110	95	32
Pb	12	21	43	*108	26	21	9	24
Rb	82	92	45	14	10	0	56	228
Sr	100	93	200	451	114	113	321	92
Y	44	18	24	11	2	25	15	58
Zr	133	164	216	335	174	181	136	147
Nb	14	9	10	8	11	13	6	30
Mo	2	9	12	11	24	12	1	8
Ba	453	477	450	518	204	182	383	459

*Concentrations in some samples of the group are higher than the upper limit of calibration range.

for analysis are believed to represent samples of the volcanic protolith, because they were collected outside the area of pervasive hydrothermal alteration and have primary textures similar to altered volcanic rocks in the mine. The composition of the unaltered metavolcanic rocks — SiO_2 usually >70%; Al_2O_3, 11-19%; Fe_2O_3, 2.0-4.1%; MgO, 0.1-0.8%; Na_2O, 0.0-5.1%; K_2O, 2.1-3.9% (Figure 4) — is similar to the average composition of rhyolite compiled by LeMaitre (1976) (SiO_2, 72.8%; Al_2O_3, 13.2%; Fe_2O_3, 2.71%; MgO, 0.39%; Na_2O, 3.55%; K_2O, 4.30%) and falls within the range of analyses for felsic volcanic rocks from Albemarle, North Carolina and McCormick, South Carolina-Lincolnton, Georgia reported by Feiss (1982). An important point is the narrow range of SiO_2 and Al_2O_3 for all the samples even though the rock type ranges from tuff to breccia and flow. The mafic unit reported by Nystrom (1972) was not analyzed in this study.

The metasedimentary rocks, stratigraphically overlying the metavolcanic rocks, have a different composition: SiO_2, 52-56%; Al_2O_3, 17-26%; Fe_2O_3, 5.7-12.3%; MgO, 0.4-4.3%;, Na_2O, 0.0-1.7%; K_2O, 1.3-6.0% (Figure 4). The metasedimentary rocks (mudstone and argillite) have very low CaO, similar to the metavolcanic rocks (<0.2%). One sample of argillite has a relatively higher CaO content (4.25%), probably due to the presence of epidote in the rocks. Compared to the metavolcanic rocks, the metasedimentary rocks are slightly higher in TiO_2 and in some trace elements (V, Cr, Co, Ni, Zn; Table 2), but the available data does not permit a detailed comparison between the volcanic and sedimentary rocks.

Geochemical signatures of the alteration zones

Major element geochemistry

Overall, rocks within the Brewer alteration zone have a wide range of composition: SiO_2, 61-91%; Al_2O_3, 7-25%; Fe_2O_3, 0.12-8.34%; K_2O, 0.01-4.10%; Na_2O, 0.00-3.70%; and MgO, 0.01-1.00%. The rocks contain very little CaO (0.2%). Figure 5 is a Al_2O_3-SiO_2 plot for the unaltered and altered volcanic rocks. Rocks from the sericitic and advanced argillic alteration zones have a large range of SiO_2 compared to those from the silicic breccia zone. However, many of the silica-rich samples from the silicic zone are not represented here, because the high SiO_2 contents (typically 90%) fall outside the SiO_2 range of calibration protocol. Petrographic studies indicate that these rocks are composed mainly of quartz with pyrite, as discussed in the previous section. The breccia pipes in the southern part of the sericitic zone have a similar composition as the silicic breccia rocks in the central zone.

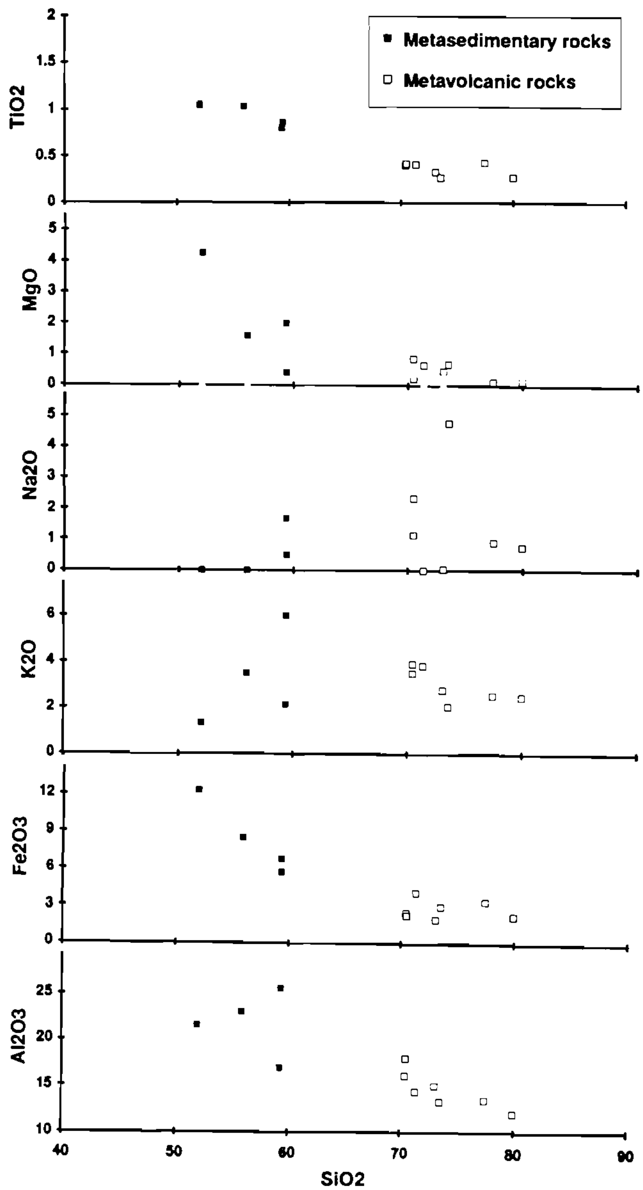


Figure 4. Plots of various major elements vs. SiO_2 of hosting metavolcanic rocks and overlying metasedimentary rocks in the Brewer mine area.

Figure 6 illustrates the relationship between Fe_2O_3 and SiO_2. Fe_2O_3 varies widely in the rocks, especially in the sericitic and advanced argillic alteration zones, compared to the unaltered volcanic rocks. The relatively lower Fe_2O_3 of the silicic zone rocks probably reflects a bias in that many of the pyrite-rich samples were not analyzed.

Figure 7 is a plot of K_2O-SiO_2, Na_2O-SiO_2 and MgO-SiO_2 for the rocks. The most obvious feature is the extremely low K_2O in the silicic zone and breccia

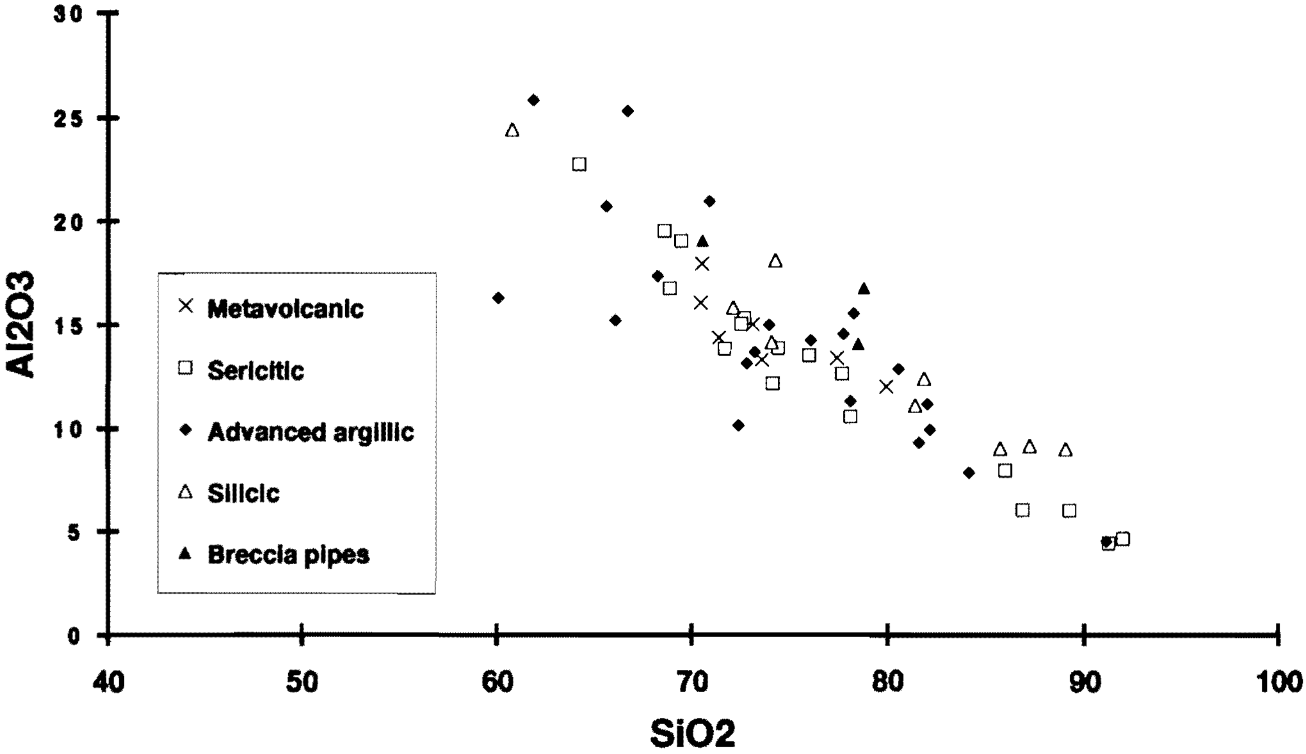


Figure 5. A plot of Al_2O_3 vs. SiO_2 of the rocks from Brewer alteration zones. Note that the rocks are grouped based on the alteration types.

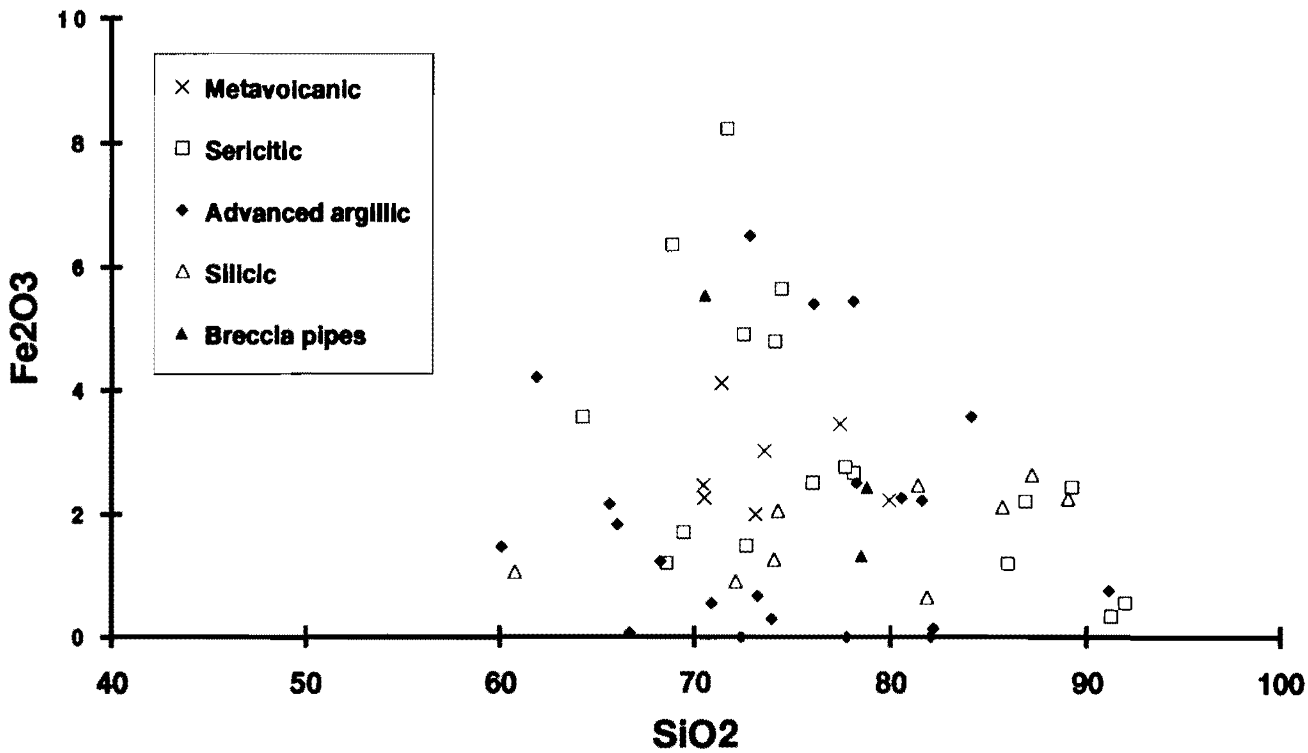


Figure 6. A plot of Fe_2O_3 vs. SiO_2 of alteration rocks.

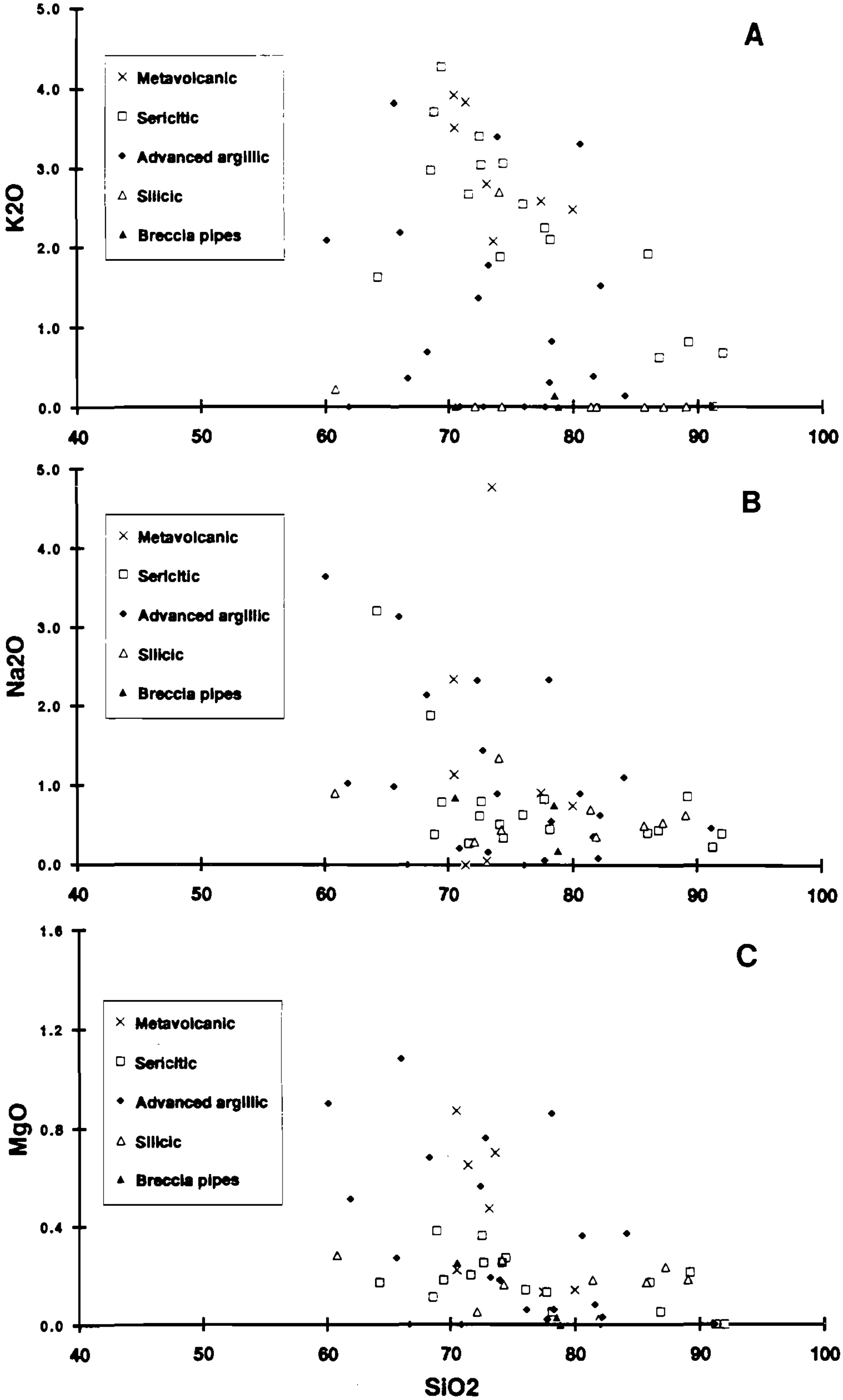


Figure 7. Plots of K_2O, Na_2O and MgO vs. SiO_2 of altered rocks. Note that the silicic zone has very low concentrations of K_2O, Na_2O and MgO.

pipes (Figure 7a). The rocks from the sericitic and advanced argillic zones have a wide range of K_2O, but all altered rocks show some depletion relative to the unaltered volcanic rocks. Na_2O, for the most part, is also low (<2%) in the alteration zones (Figure 7b). Alunite-bearing rocks have relatively higher Na_2O (2.3-3.6%), significantly higher than other rocks in the same zone (<2%). The composition of alunite in the Brewer mine is apparently a K-Na solid solution, as indicated by X-ray diffractometric patterns. MgO is very low in the rocks, usually less than 1% (Figure 7c). In the advanced argillic zone, MgO shows a relatively wider range, probably due to the presence of some Mg-bearing alteration minerals, such as lazulite.

Overall, the hydrothermally altered rocks are depleted in alkali relative to unaltered volcanic rocks (Figure 8). Alunite-bearing samples have higher alkali concentrations. Rocks from the silicic zone and breccia pipe are very low in alkali. The metavolcanic rocks appear to be tholeiitic, similar to the volcanic rocks in the Albemarle, North Carolina and the McCormick, South Carolina-Lincolnton, Georgia area (Feiss, 1982).

A TiO_2-SiO_2 plot (Figure 9) shows that TiO_2 varies mainly between 0.2 % and 0.6% in altered rocks. The metasedimentary, contact metamorphic and granitic rocks mainly have higher or lower TiO_2.

The major elements show some systematic variations among the different alteration zones (Figure 10). SiO_2 increases slightly from the outer to the inner zone; whereas, K_2O and Na_2O are depleted. Fe_2O_3 increases slightly in the sericitic zone, then decreases toward the advanced argillic zone. Al_2O_3 shows little variation throughout the zones, even though some andalusite-rich samples have relatively higher values. The same observation was noted with TiO_2. Ti and Al seem to have behaved as immobile elements during hydrothermal alteration.

Trace element geochemistry

Fourteen trace elements (Cu, Zn, Pb, Mo, Ni, Cr, Co, V, Rb, Sr, Y, Zr, Nb, Ba) were analyzed. Based on abundance, these elements fall into three groups. The first group, Co, Cr, Ni and Nb, has concentrations usually less than 10 ppm in most rocks. The second group, Cu, Y, Mo, Pb, Rb and Zn, has concentrations usually between 10 and 100 ppm. The third group, Ba, Sr, Zr and V, has concentrations usually greater than 100 ppm (Figure 11).

From a geochemical study of the interior part (silicic and advanced argillic zones) of the Brewer system, Jaacks (1986) concluded that the breccia has a distinctive chemical signature involving the elements Fe, Mn, Cu, Mo, As, Ag, Mg, Au and Hg. Ti, V, Al, P and Ha were found to be associated strongly with the metavolcanic rocks adjacent to the breccia. Sr, Pb, Ba, Na, Al and K showed a strong association with the metavolcanic rocks within structural zones. Ni, Co and Zn were typically below detection limits. Mo, Cr, V and Cu were usually between 10 and 100 ppm; and Sr, Ba and Pb were usually greater than 100 ppm. Our study shows similar concentrations of Co, Ni, Mo, Cu, Cr, Sr and Ba; but, Zn and V concentrations are much higher and the advanced argillic alteration zone is characterized by relatively abundant Sr, Zr, Zn and Ba.

Figure 11 shows the variation of trace element abundances among the different alteration zones. One obvious trend is the depletion of many elements in the silicic zone. This could have been a result of a strong hydrothermal leaching process in the breccia zone leading to the removal of most of the elements, although the sample selection could also have introduced some bias. Overall, Cu, Sr, Zr, Pb and Zn are enriched; whereas, Rb and Y are depleted toward the center of the system.

The trace element abundance in the rocks can vary greatly, even within the same zone. Some elements, like Pb, Zn and Sr, can be quite high in some samples and fall outside of the calibration's upper limit. The true abundance of an element could not be determined in such cases, although a minimum concentration could be estimated. The variations in abundance could have resulted from the mineral assemblages, channelized flow paths and host rock compositions.

Plutonic and contact metamorphic rocks

A few samples of the Pageland pluton and its contact metamorphic rocks were analyzed (Table 2). The quartz monzonite of the Pageland pluton has a composition of typical granite (LeMaitre, 1976). The contact metamorphosed volcanic rocks exhibit some chemical variations compared to the unaltered volcanic rocks. The most obvious differences are the relatively abundant MgO (3.51%) and CaO (5.31%) in the hornfels, represented by the abundance of epidote, amphibole and calcite. The contact metamorphosed volcanic rocks also have higher Na_2O and lower SiO_2. The higher concentrations of MgO, CaO and Na_2O in the contact metamorphic rocks indicate that magmatic fluids expelled from the granitic intrusion probably were enriched in these elements. The extremely low CaO and MgO contents of the Brewer altered rocks indicate that the Brewer hydrothermal alteration was not related to the Paleozoic magmatic (intrusive) activity.

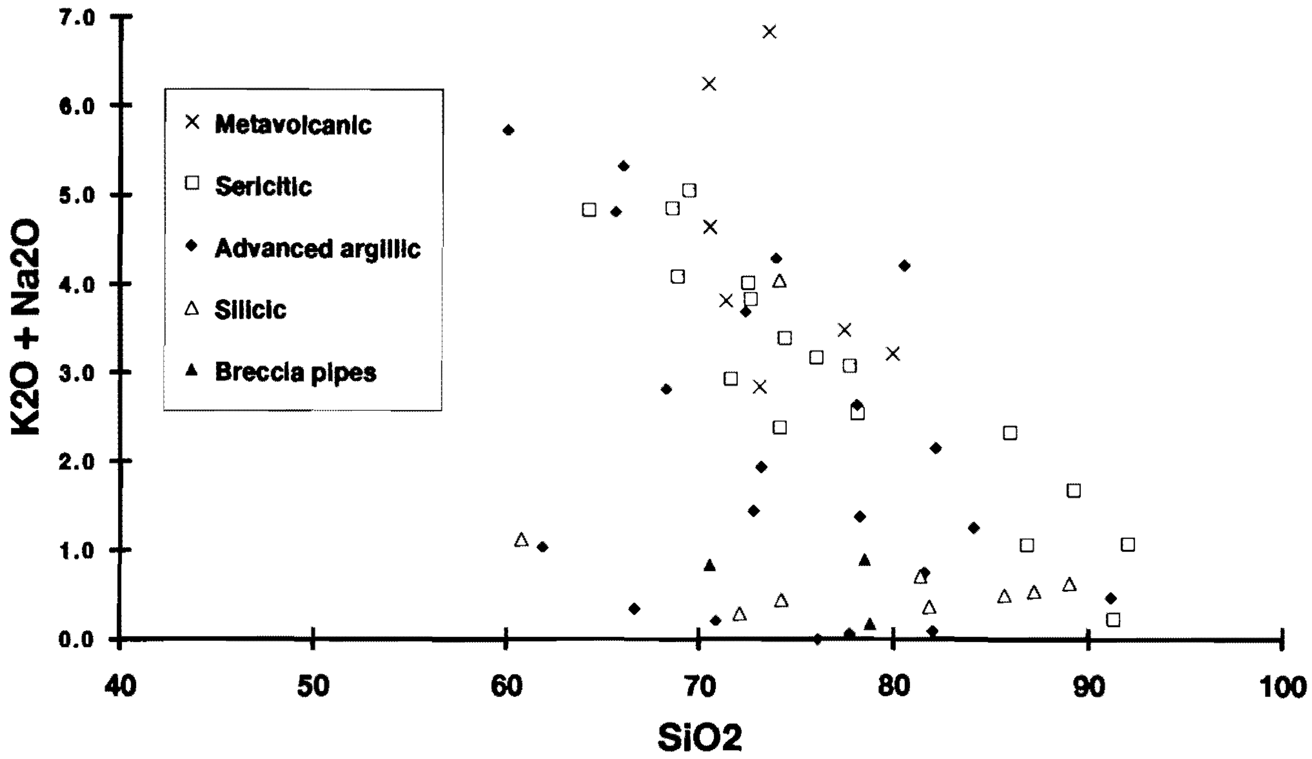


Figure 8. An alkali-SiO_2 plot of altered rocks showing the depletion of alkali (Na2O + K_2O) toward the center of the Brewer system. The host volcanic rocks represent a tholeiitic suite.

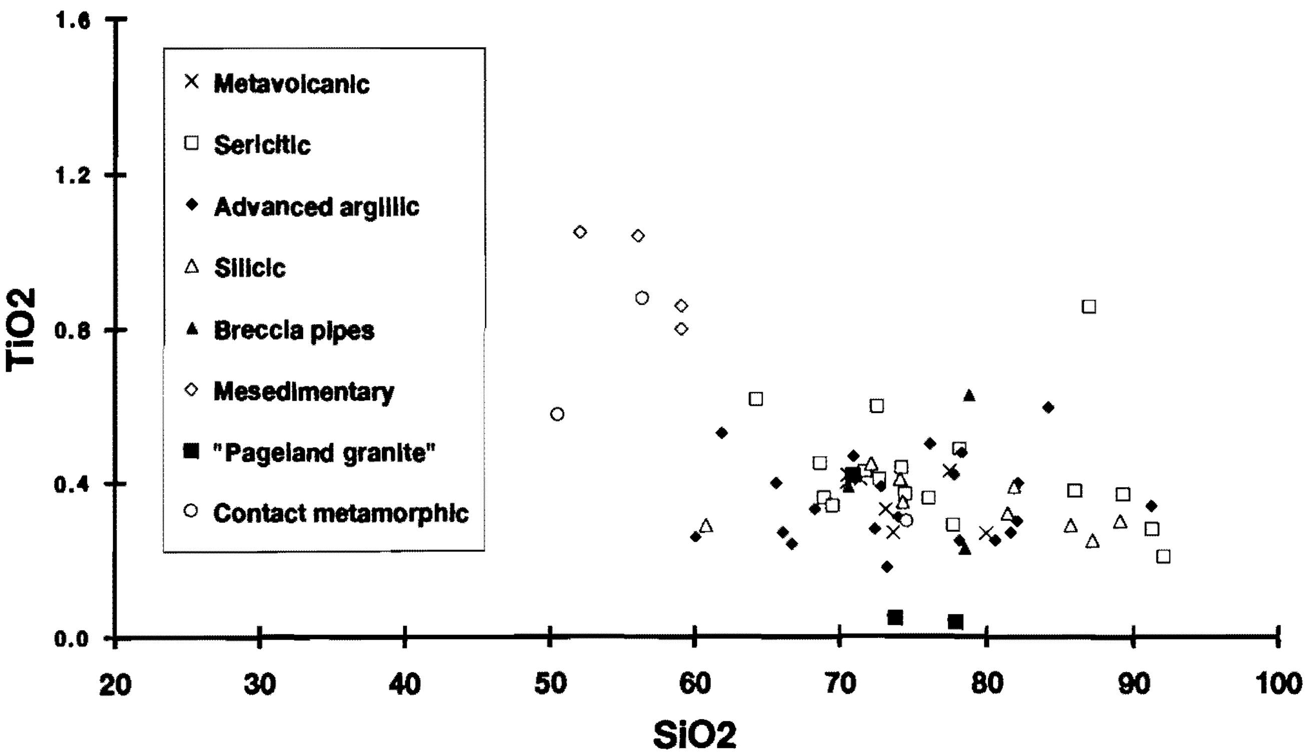


Figure 9. TiO_2-SiO_2 plot showing the relatively uniform content of TiO_2 throughout the alteration zones.

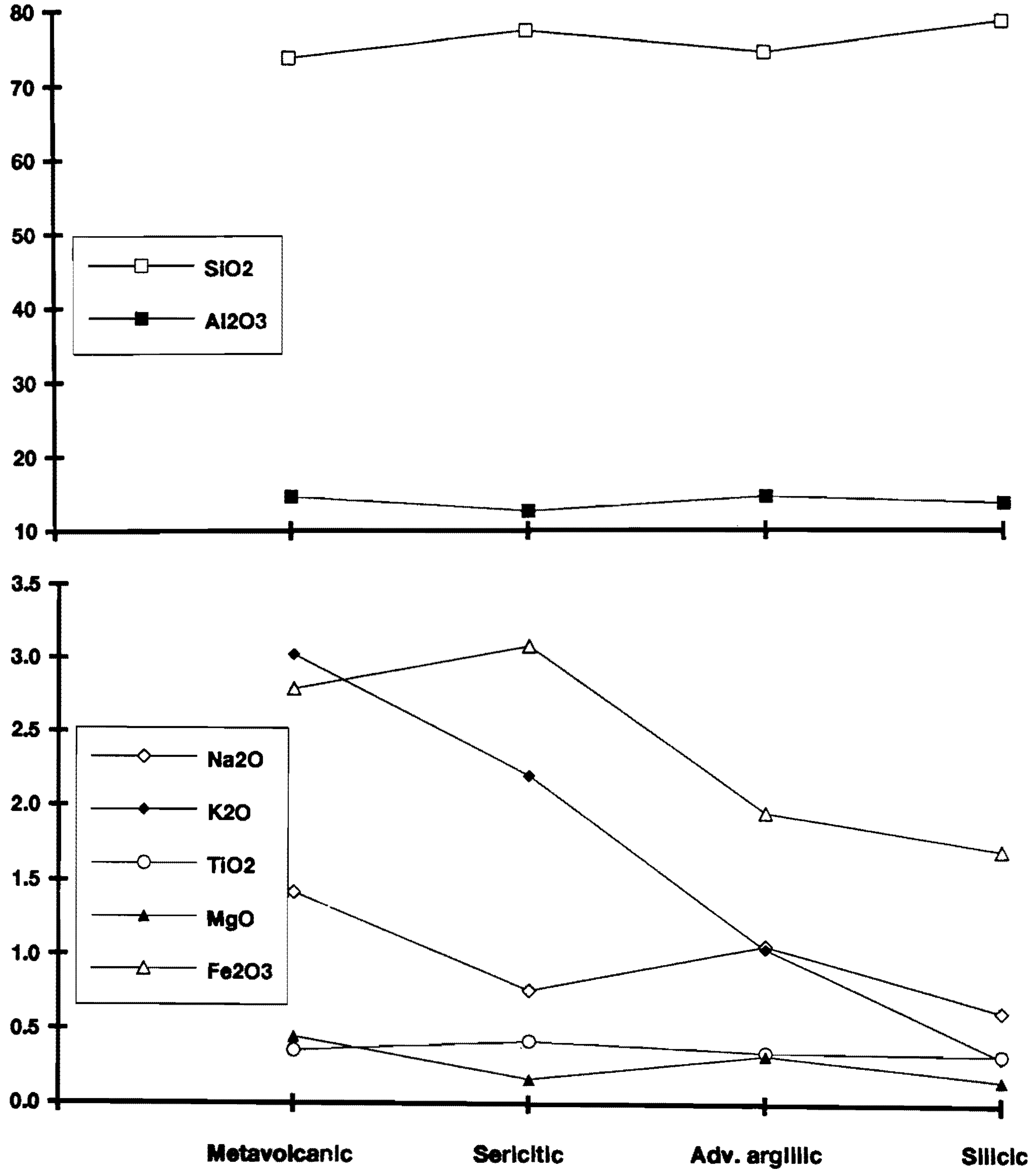


Figure 10. Diagram showing the zoning of major elements in altered rocks. SiO_2 increases towards the center; whereas, K_2O, Na_2O and MgO decrease. TiO_2 and Al_2O_3 are relatively constant. Note the depletion of most elements in the silicified zone (quartz + pyrite), suggesting leaching during hydrothermal alteration.

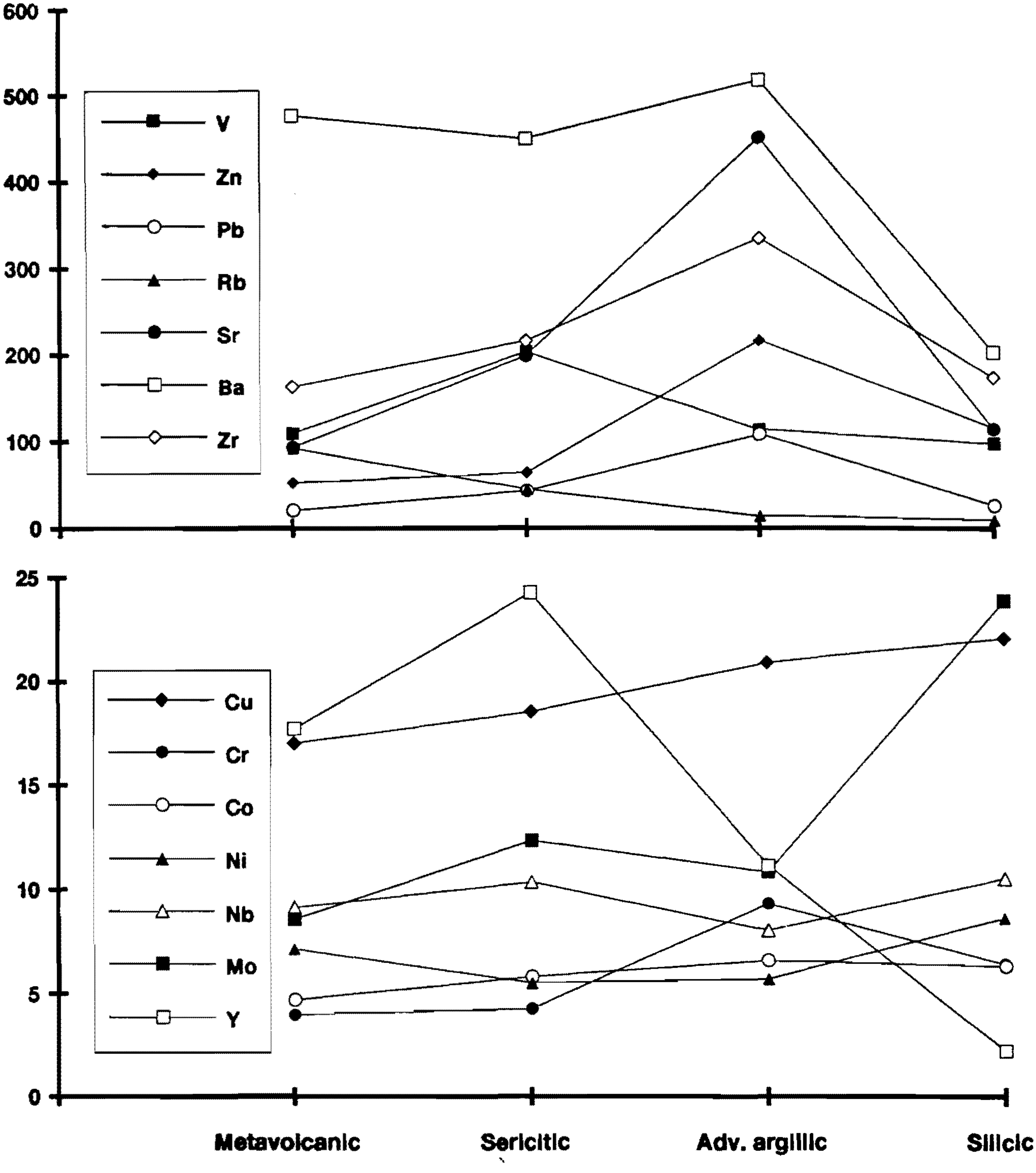


Figure 11. Diagram showing the zoning of minor and trace elements in altered rocks.

Discussion

Formation of the geochemical zonation and implications

The geochemical zonation in the Brewer area is the result of hydrothermal alteration. During hydrothermal alteration, fluids circulated and penetrated through the rocks, reacting with the original volcanic rocks and forming hydrothermal alteration minerals. The minerals formed depended on the original rock composition, fluid composition and P-T conditions.

The host volcanic rocks are very heterogeneous, tuffs to flows and breccias in the Brewer area. Many of these rocks may have formed at different phases in a single volcanic system, resulting in some variation of the original chemical compositions of the host rocks. The heterogeneity of the host rocks certainly would affect the geochemical signatures of the altered rocks. However, the volcanic rocks appear to be a reasonably cohesive group and originally felsic in composition (Figure 4).

The mineralizing hydrothermal fluids probably were acidic (low-pH) and sulfur-rich. This is suggested by the presence of abundant sulfide minerals, including pyrite and enargite (Cu_3AsS_4), and an acid-sulfate alteration mineral assemblage quartz-alunite ($KAl_3(SO_4)_2(OH)$) in the interior part of the hydrothermal system. Geochemical comparison between the hydrothermally altered and unaltered volcanic rocks suggests that the altered rocks are enriched relatively in Si, Cu, Mo, Zr, Sr and Pb, all of which were introduced by the hydrothermal fluids. The dominance of pyrite-quartz breccia in the interior part of the system indicates that the mineralizing fluid was enriched in iron and sulfur toward the end of the hydrothermal evolution. Many aspects of the hydrothermal system, such as, fluid source and composition, metal transport and precipitation mechanism, would be better understood by combining this study with fluid inclusion and stable isotope studies that are in progress.

The P-T conditions of the Brewer hydrothermal alteration are not well understood. Temperatures as high as 300-400°C in the interior zone of the system are likely, based on andalusite-quartz mineral assemblage (Scheetz, 1991) and preliminary fluid inclusion studies. Scheetz (1991) suggested a shallow near surface emplacement for the Brewer system, based on the presence of layered siliceous sediments and siliceous clasts within andalusite-quartz rocks, quartz-sericite rocks and metamudstones.

Regional metamorphic effects on the alteration zones

The well-preserved alteration zones and accompanying geochemical zonation indicate that the regional metamorphism has not affected significantly the chemistry of the rocks. Some metamorphic minerals, such as chloritoid and kyanite, are present only sporadically in the alteration halo. The composition of the chloritoid-bearing sericite schist is similar to other rocks in the sericitic zone. In the central part of the system (silicic zone), the metamorphic overprint is minimal. Around the central zone, the metamorphic grade is only chlorite- to biotite-grade of the lower greenschist facies. All this suggests that the rocks have been deformed to some degree, but the coeval metamorphism was perhaps an isochemical process; that is, there has been little chemical and mass transfer over a large area during the regional metamorphism, although some metals might have been remobilized along fracture zones on a local scale.

Comparison with younger epithermal deposits

Many characteristics of the Brewer deposit, including structural setting, host rocks, alteration types, alteration mineralogy and sulfide mineralogy are similar to those of epithermal acid-sulfate type deposits (Hayba and others, 1985; Heald and others, 1987), even though some metamorphic features (metamorphic minerals and foliation) exist at the Brewer mine (Table 2).

Hayba and others (1985) and Heald and others (1987) summarized the general characteristics of the epithermal acid-sulfate deposits. Acid-sulfate deposits are spatially related to intrusive centers, particularly ring-fracture volcanic domes on the margins of calderas. They typically are hosted by rhyodacitic volcanic rocks and are characterized by the occurrence of the vein mineral assemblage enargite+pyrite+covellite in an advanced argillic alteration zone, which is often coextensive with silicification and is surrounded by sericitic and propylitic alteration zones. The Brewer gold mine exhibits most of these features. The mine is hosted by felsic (rhyolitic) rocks in the center of a volcanic system, a cinder zone or a caldera (Nystrom, 1972). The gold mineralization, associated mainly with pyrite-quartz±enargite breccias, is accompanied by silicic, advanced argillic, sericitic and, to a limited degree, propylitic alteration zones in a concentrically zoned pattern.

Table 2. Comparison between the Brewer gold deposit and typical epithermal acid-sulfate type deposits.

	Epithermal Acid-sulfate Deposit	Brewer Mine
Host Rocks	rhyodacite to rhyolite	rhyolite
Sulfide minerals	enargite, pyrite, gold, base-metal sulfides	enargite, pyrite, gold, base-metal sulfides
Alteration	silicic advanced argillic to argillic sericitic	silicic advanced argillic sericitic
Alteration Pattern	relatively small, equidimensional	concentric
Alteration Minerals	alunite, sericite, kaolinite	alunite, sericite, kaolinite, andalusite
Temperature	200 to 300°C	200 to 350°C (fluid inclusion data)
Fluid Composition	variable salinity (1-24 wt% NaCl eq.), trace CO_2	H_2O-CO_2-(?)saline (salinity undetermined)

However, some features, especially the widespread aluminosilicate alteration complex and the abundance of andalusite in the advanced argillic alteration zone of the Brewer area, are not present in typical acid-sulfate type deposits, which has led to the suggestion of different types of hydrothermal systems (Schmidt, 1985; Worthington and others, 1980). The origin of the andalusite has been attributed to hydrothermal alteration in a porphyry system (Schmidt, 1978; 1985) and metamorphism (Ririe, 1990). More recently, Scheetz (1991) has suggested that much of the andalusite was formed during the prograde metamorphism after hydrothermal alteration had occurred. However, geochemical analyses presented herein suggest that overall Al is not particularly enriched in the advanced argillic alteration zone. Rather, Al appears to have been immobile during the hydrothermal alteration.

Conclusions

1. Hydrothermal alteration associated with gold mineralization in the Brewer area produced a crude concentric zoning pattern, consisting of silicic (quartz-pyrite breccia), advanced argillic (alunite-quartz-andalusite) and sericitic (quartz-sericite) rocks. The geologic setting, alteration pattern and alteration mineral assemblages suggest that the deposit is an epithermal acid-sulfate type deposit.

2. The protoliths of the metavolcanic rocks, the hosts for gold mineralization and hydrothermal alteration at the Brewer, are mostly felsic volcanic rocks with an overall rhyolitic composition. The alkali index of the rocks suggests that they have a tholeiitic affinity. The metasedimentary rocks overlying the metavolcanic rocks are quite different in composition, characterized by lower SiO_2 and higher Al_2O_3, Fe_2O_3 and MgO.

3. The hydrothermal activity resulted in some chemical changes in the original rocks. Overall, the hydrothermally altered volcanic rocks are relatively enriched in SiO_2 and depleted in K_2O and Na_2O compared to the unaltered volcanic rocks. The altered volcanic rocks also have relatively higher abundances of Sr, Cu, Mo, Pb and Zr. Some elements show a systematic geochemical zonation. SiO_2, Cu and Mo are enriched toward the center of the system; whereas, K_2O, Na_2O, Y, Pb and V are depleted.

4. The hydrothermal fluids were probably acidic and sulfur-rich, as indicated by the presence of high-sulfur minerals such as alunite, enargite and abundant pyrite in the central alteration zone of the system. The hydrothermal fluids probably were enriched also in Fe, Cu, Mo, Zr, Pb and other metals, as inferred from the geochemical signature of the rocks.

5. The well-preserved acid-sulfate type alteration pattern and mineral assemblage in the Brewer mine area suggest that subsequent regional greenschist facies metamorphism did not change significantly the geochemical signature of the altered rocks, although it may have resulted in localized gold remobilization.

Acknowledgements

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GEOCHEMICAL PROFILES OF SIX REVERSE-CIRCULATION DRILL HOLES FROM THE BARITE HILL GOLD DEPOSIT, SOUTH CAROLINA

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Abstract

Splits of 5-foot interval samples from six reverse-circulation drill holes taken from the Barite Hill gold deposit in the southern part of the Carolina slate belt were analyzed chemically using several methods. The most useful results were obtained from inductively coupled plasma-atomic emission spectrometry (ICP-AES) for 10 elements and atomic absorption spectrometry (AAS) for Au and Te. Weathering and overprinting of successive generations of mineralization at Barite Hill are reflected in variations in geochemical profiles. Elements that persist to the surface include Au, Ag, Bi, Sb, As and Mo; while Cu, Pb, Zn, Cd, Hg and sometimes Ag, Te and Tl show a variable, but generally strong, depletion in the oxidized zone. Chemical distribution patterns show a Au-Ag-Te association that probably is related to a gold-rich stage of mineralization. Other elements that form distinct groups are Bi, Sb, As and Mo, which are related to Au and Ag; and Cu, Pb, Zn and Cd, which are related to Ag, but show little or no relation to Au. A Ag-Te-Bi-Sb-As-Mo-Cu-Pb-Zn-Cd association seems to characterize a gold-poor, base-metal-rich stage of mineralization; whereas, the Cu-Pb-Zn-Cd association reflects a base-metal sulfide-rich stage of mineralization that does not contain anomalous Au.

Introduction

The Barite Hill mine went into production in 1991, making it the fourth gold mine to begin operations in South Carolina during the last decade. Exploration has been conducted in the Barite Hill area since the mid-1970's, first for base metals, later for barite, and then for precious metals. Exploration work by Amselco Exploration, Inc., from 1985-88, resulted in unpublished maps and an unpublished report (Padgett and Watkins, 1988), which included data from trenches, diamond drill core and outcrop. The property, geologic reports and drill core were purchased by Gwalia (U.S.A.) Ltd. in 1988, and further exploration using reverse-circulation drilling was undertaken. Chemical analyses of samples by the U.S. Geological Survey from some of the reverse-circulation drill holes were done in cooperation with Gwalia (U.S.A.) Ltd. to determine what types of analyses might be used to characterize the distribution of elements in the deposit. This geochemical study of reverse-circulation drill-hole samples has led to a more extensive study of diamond drill core and outcrop in the region. This interim report makes available geologic maps, results of the geochemical study, and preliminary observations and interpretations from work in progress.

Geologic setting

The Barite Hill gold deposit is located in the southern part of the Carolina slate belt, near McCormick, South Carolina, in the Lincolnton-McCormick district of South Carolina and Georgia (Figure 1). The district contains numerous gold, silver and base-metal mines and prospects on the flanks of the Lincolnton metadacite described by Carpenter and others (1982). Mines with past production include the Dorn mine at McCormick, South Carolina, the Searl's, Pig Farm and Jennings mines near Barite Hill; and the Civil War and Magruder mines near Lincolnton, Georgia. The district also includes several zones rich in aluminum-silicates, including the Graves Mountain, Georgia kyanite mine and andalusite outcrops near the Pig Farm mine.

The Lincolnton-McCormick district is in greenschist-

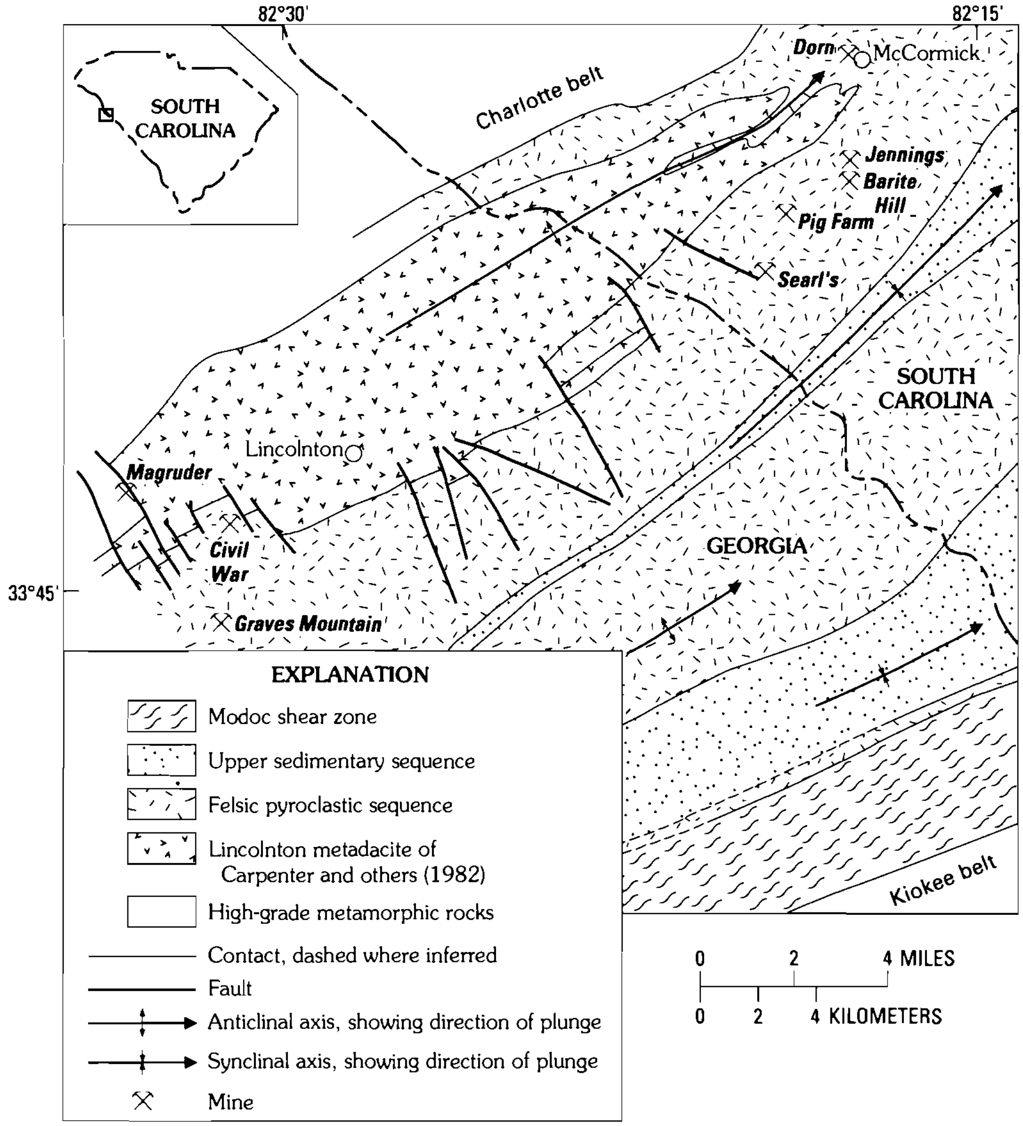


Figure 1. Map showing the regional geologic setting of the Barite Hill gold deposit and other deposits in the Lincolnton-McCormick district of South Carolina and Georgia. Adapted from Carpenter, 1982; Secor, 1987; and Butler and Secor, 1991.

facies metamorphic rocks of the Carolina slate belt between high-grade metamorphic rocks of the Kiokee and Charlotte belts. The district is north of the Modoc shear zone and south of the Lowndesville shear zone. Gold mineralization at Barite Hill is in a felsic pyroclastic sequence, which lies between the Lincolnton metadacite and an upper sedimentary sequence (informal, locally used names). The Lincolnton metadacite, which is thought to be an Early Cambrian intrusive-extrusive complex, yielded primary ages of 554±20 Ma (Rb-Sr) and 566±15 Ma (U-Pb, zircon) (Carpenter and others, 1982). The felsic pyroclastic sequence is thought to be composed of debris derived mainly from a volcanic center related to the Lincolnton metadacite (Carpenter and others, 1982). The felsic pyroclastic sequence and upper sedimentary sequence are probably correlative with the Persimmon Fork and Richtex formations of central and northern South Carolina, respectively (Carpenter and others, 1982).

The Barite Hill mine consists of two areas, the main pit, which is characterized by gold deposition in distinctive quartz-barite-rich zones, and the Rainsford South, which lacks barite-rich rocks (Figure 2). Gunter (unpublished map, 1986) differentiated units of mainly volcanic origin from units of mainly sedimentary origin in the pyroclastic sequence. The general strike of the

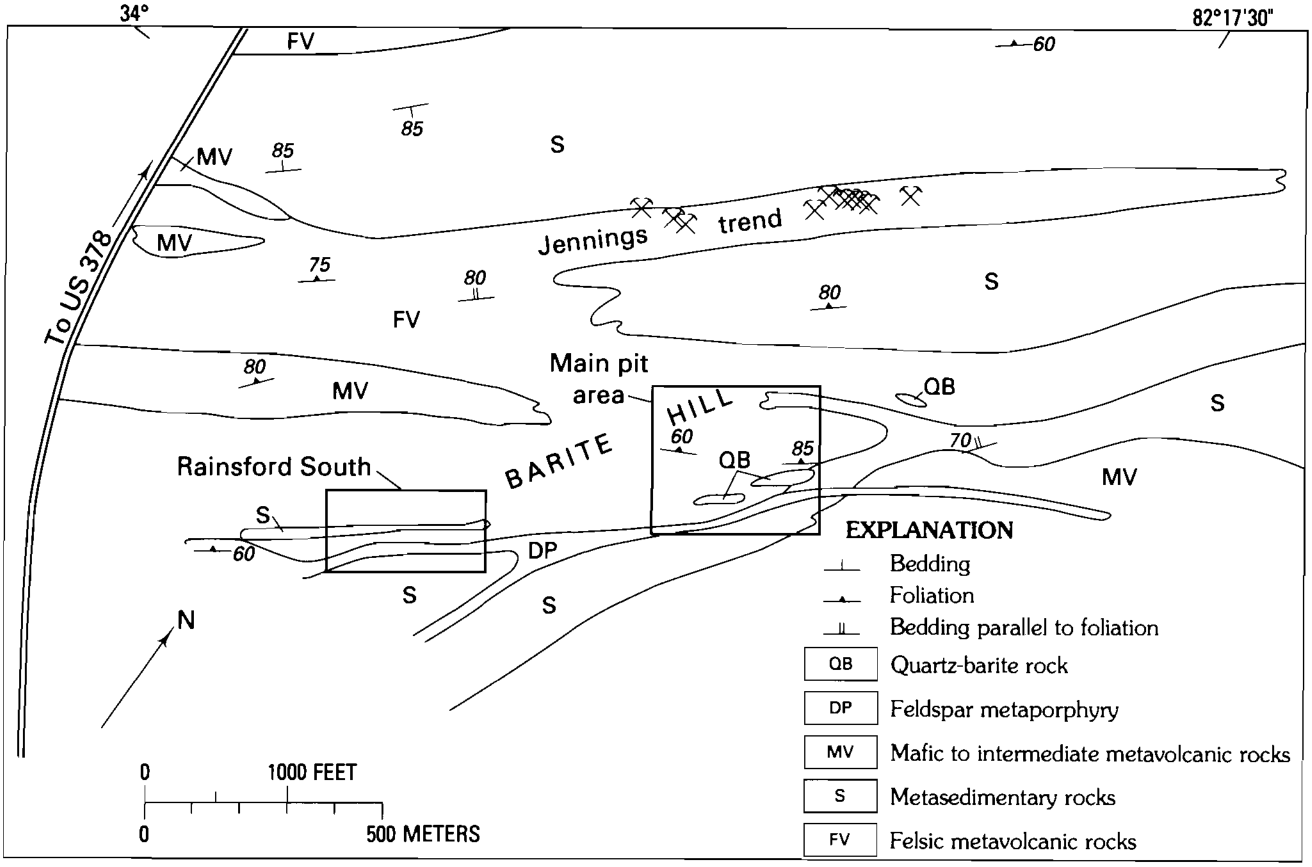
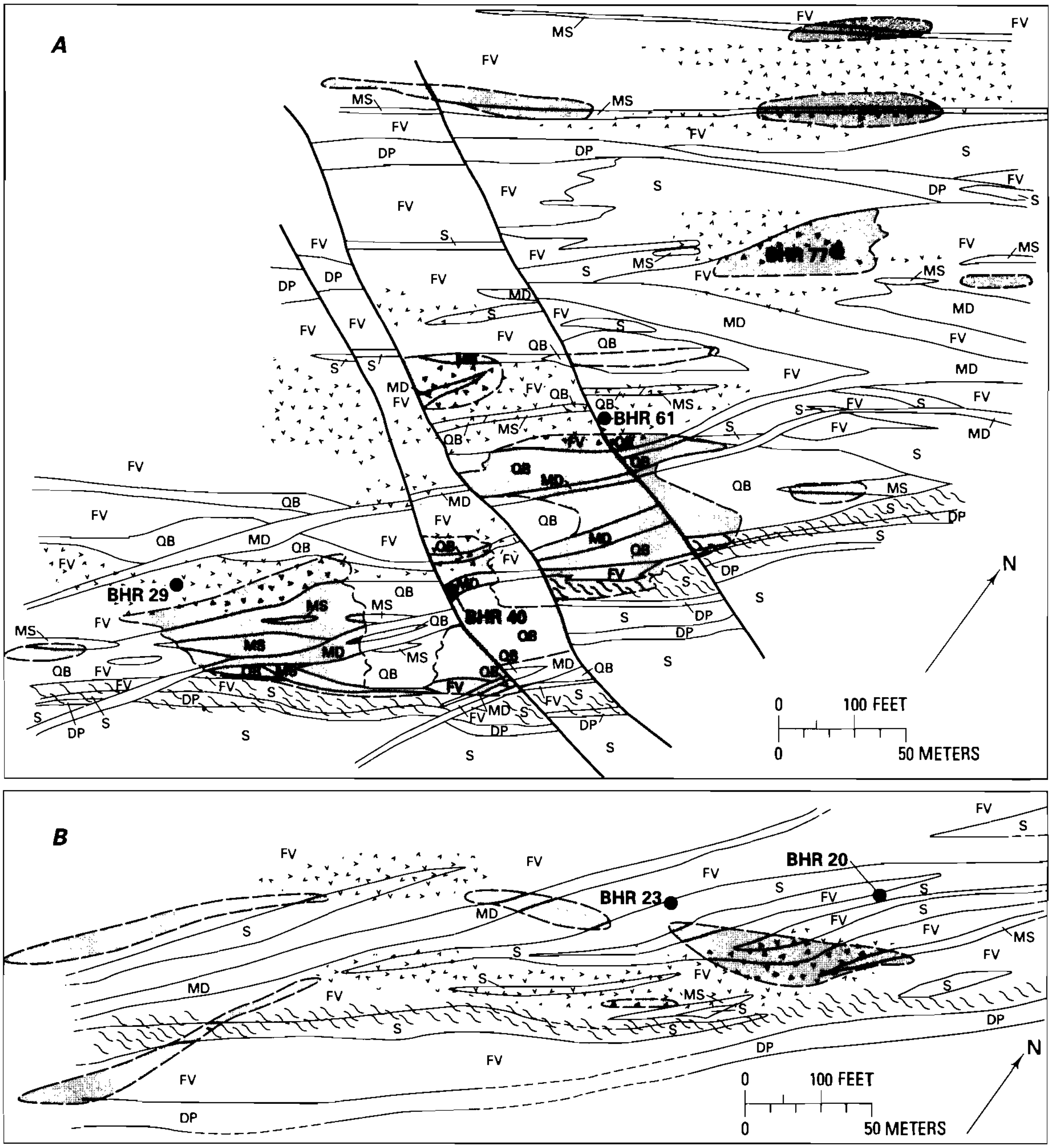


Figure 2. Map showing the location and geologic setting of the Barite Hill gold deposit. Adapted from Gunter, 1986, unpublished map. Boxes outline areas shown in more detail in Figure 3.

schistosity is between 50° and 55° NE; dip is about 75° NW. Schistosity commonly developed both parallel to bedding and at about 10° from the bedding-parallel schistosity, with fabrics and orientations that indicate a relationship to folding and shearing during at least two deformational events (S.H.B. Clark, unpublished data; Terry Offield, 1991, oral communication). Lithologic units dip steeply to the northwest. Where tops can be identified in outcrop or diamond drill core, they indicate overturned bedding, which is consistent with regional interpretations that the section becomes younger to the southeast (Whitney and others, 1978).

At Barite Hill, the felsic metavolcanic unit is typically composed of fine-grained, sericitic metatuffs, commonly with quartz eyes, but also includes coarse-grained metatuffs and metabreccias (Figure 3). The metasedimentary unit includes medium- to coarse-grained, mainly epiclastic rocks that are typically chloritic and contain a variety of crystal fragments, including feldspar, quartz (commonly blue) and lithic clasts. Graded bedding is preserved locally in sandstone and siltstone layers. Very fine-grained, laminated rocks include argillites and siliceous layers that commonly occur near the tops of volcaniclastic units. The mineralized zones are bounded on the south by a distinctive unit that is probably a sill or stock of dacitic composition and that herein is called feldspar metaporphyry. The rock contains subhedral feldspar and minor quartz phenocrysts in a fine-grained, feldspar-quartz-sericite-chlorite-epidote matrix. Numerous layers of fine-grained, dark-colored (dark green at depth and dark red where oxidized), mafic to intermediate igneous rock, from a few inches to a few tens of feet in thickness, are present in the section. Most layers are thought to be dikes or sills, but some have amygdaloidal tops and are probably flows. Lenses of submassive to massive sulfide are oxidized to gossans at the surface and in oxidized parts of the core. The unoxidized sulfide-rich rock contains mostly pyrite and volumetrically minor amounts of chalcopyrite, galena and sphalerite. Quartz-barite-rich rocks with granular to coarse, bladed textures form prominent outcrops in the southeast part of



EXPLANATION

QB	Quartz-barite rock
MS	Sulfide-rich rock. Gossan in oxidized zone, massive sulfide where unoxidized
MD	Mafic to intermediate dike or sill. Massive to weakly foliated
DP	Feldspar metaporphyry. Massive to weakly foliated intrusive body of probable dacitic composition
S	Metasedimentary rocks. Thinly bedded to finely laminated, medium- to fine-grained rocks interlayered with felsic crystal vitric tuff and medium- to coarse-grained, volcaniclastic sandstones to conglomerates
FV	Felsic metavolcanic rocks. Fine-grained, sericitic metatuffs, commonly with quartz eyes; includes medium- to coarse-grained metatuffs and metatuff breccias
	Fragmental rocks
	High gold zone (average ≥ 1 ppm)
	Shear zone
	Contact, dashed where indefinite
	High-angle fault
●	Reverse-circulation drill hole

the main pit area of Barite Hill.

Zones of fragmental rocks mapped by Padgett and Watkins (1988) are typically heterolithic breccias in which clasts are composed mostly of felsic volcanic material. Some of the breccias are matrix supported and others are clast supported. Some of the breccias may be of pyroclastic origin, and most show evidence of shearing in the matrix, suggesting that the fragmental rocks could include tectonic breccias or be pyroclastic breccias with tectonic overprinting. A significant feature of the fragmental rocks is the presence of pyritic and siliceous veinlets in many of the breccias (Clark and others, 1992). The veinlets are most common in the matrix, but they also cut clasts and earlier veinlets in intensely veined rocks. These veinlets are interpreted to have formed from hydrothermal fluids that moved preferentially through permeable zones in the fragmental rocks.

A zone of moderate to intense ductile shearing that bounds and locally has redistributed mineralized rock (Padgett and Watkins, 1988) is near the southern border of the map area (Figure 3). Late, steeply dipping, northwest-trending faults, which are probably related to Mesozoic extension, cut lithologic units, mineralized zones and the ductile shear zone. In drill core, the late fault zones consist of clay, some of which has been identified as kaolinite (J.W. Hosterman and S.H.B. Clark, unpublished data).

The mineralized zones at Barite Hill are lenses that locally cut lithologic contacts. In the main pit area, the most intense mineralization is generally within, but not confined to, the quartz-barite zone. Gold values drop off abruptly in the shear zone, feldspar metaporphyry, mafic igneous rocks and clay zones associated with late faults. The highest gold values are associated with the felsic metavolcanic host rocks, especially in zones where fragmental rocks are cut by quartz-pyrite veinlets and in quartz-barite rock. Sericitic (illite and muscovite) alteration is widespread, but gold is associated with the more localized quartz-pyrite±barite alteration. Two stages of gold mineralization have been identified at Barite Hill (Gunter and Padgett, 1988; Clark and others, 1992). Stage 1 is characterized by low gold content (average of 0.3 to 1.0 ppm) and high base-metal content. Stage 2, with a high gold content (average greater than 1.0 ppm) and low base-metal content, formed after stage 1. Base-metal sulfide accumulations with very low gold content developed locally, prior to the gold mineralization.

Figure 3. Geologic map of Barite Hill showing lithologic units, fragmental and shear zones, locations of gold-rich mineralized zones, and locations of vertical reverse-circulation drill holes selected for study in A. the main pit area and B. Rainsford South. Compiled from Padgett and Watkins, 1988.

Gold and silver occur in their native state and also in tellurides and electrum. Silver also occurs in argentite, hessite, galena and complex selenides. Other metallic minerals include chalcopyrite, bornite, sphalerite and Cu-Pb-Bi tellurides and selenides (Gunter and Padgett, 1988). Petrographic and mineralogic studies using optical and scanning-electron microscopy have shown that gold is associated with Ag and Te in areas of abundant quartz and pyrite and that phases including Ag, Cu, Pb, Mo, Bi, As, Se, Te and S occur in intergranular areas between pyrite grains and along microfractures (Back and Clark,1992).

Geochemistry of reverse-circulation drill holes

A geochemical study of splits of samples of 5-foot intervals from reverse-circulation drill holes was initiated in 1989 to determine (1) the types of routine analyses that would best characterize the Barite Hill mineralization and (2) if primary geochemical dispersion patterns could be detected in reverse-circulation drill-hole samples. Splits were made of samples from six reverse-circulation drill holes, which were selected to include both holes that intersect the ore zone and holes near the edge of the ore zone. Four of the drill holes were in an area that became the main pit when mining began late in 1990, and two were in the Rainsford South area (Figure 3). All samples were analyzed in U.S. Geological Survey laboratories using graphite furnace atomic absorption spectrometry (AAS) for Au and direct-current-arc atomic emission spectrometry for 34 elements (Ca, Fe, Mg, Na, P, Ti, Ag, As, Au, Ba, Be, Bi, Cd, Co, Cr, Cu, Ga, Ge, La, Mn, Mo, Nb, Ni, Pb, Sb, Sc, Sn, Sr, Th, V, W, Y, Zn, Zr). For samples from two holes, BHR 40 and BHR 29, additional analyses were done for Te and Tl by flame AAS, for Hg by cold-vapor AAS, and for 10 elements (Ag, As, Au, Bi, Cd, Cu, Mo, Pb, Sb, Zn) by inductively coupled plasma-atomic emission spectrometry (ICP-AES). Samples from BHR 40 also were analyzed by energy-dispersive X-ray fluorescence spectrometry (XRF) for 12 elements (Ba, Ce, Cr, Cu, La, Nb, Ni, Rb, Sr, Y, Zn, Zr). Graphs of the initial results were plotted and compared to determine the types of analyses that seemed to show variations in concentration that were related to the mineralization at concentration levels within detection ranges of the method. Examination of the graphs suggested that ICP-AES analyses for Ag, As, Bi, Cd, Cu, Mo, Pb, Sb and Zn and AAS for Au, Te, Tl and Hg seemed to provide the most potentially significant data for the deposit. Comparison of results from AAS for gold with

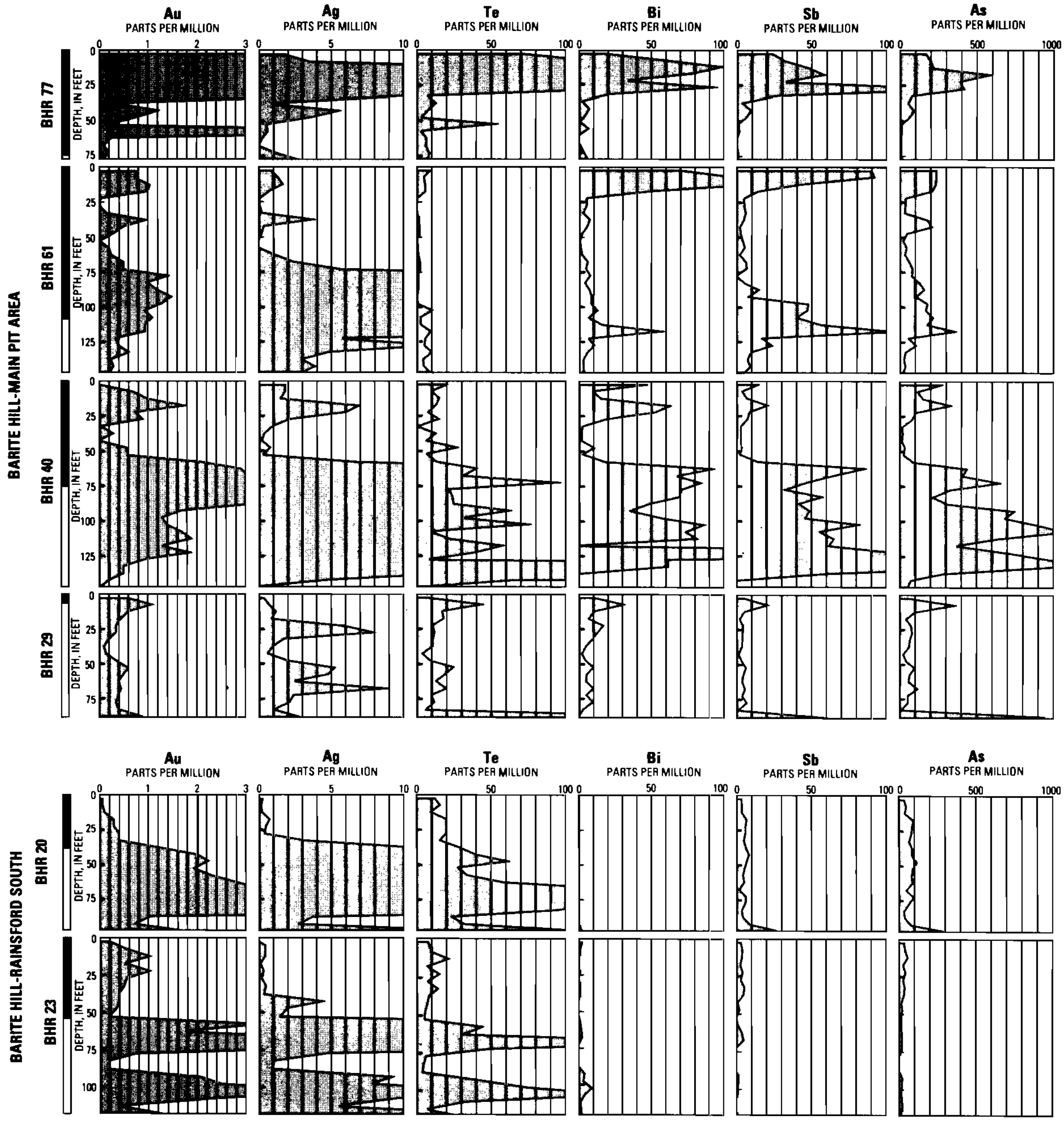


Figure 4. Geochemical profiles for selected elements in samples from six 45-degree SE reverse-circulation drill holes in A. the main pit and B. Rainsford South areas of Barite Hill. All chemical data in parts per million. Diagonal ruling on logs indicate oxidized zones, as determined by absence or presence of sulfides in samples. The presence of mafic to intermediate dikes is indicated by gray shading.

results from fire assay done in Gwalia laboratories showed closely comparable values. On the basis of the initial results, samples from BHR 77, 61, 23 and 20 were analyzed for Te, Tl and Hg by using AAS and for 10 elements (Ag, As, Au, Bi, Cd, Cu, Mo, Pb, Sb, Zn) using ICP-AES. Results of the AAS and ICP-AES analyses (Table 1) were plotted to show geochemical profiles of the drill holes (Figure 4). Plots of element pairs on logarithmic xy (scatter) graphs using data from all of the drill holes showed elongate zones of closely spaced points for some element pairs and widely scattered data for others (Figure 5). These graphs were used to supplement drill-hole profiles to identify groups of associated elements.

In BHR 77, high Au values correspond in a general way to high concentrations of Ag, Te, Bi, Sb, As and

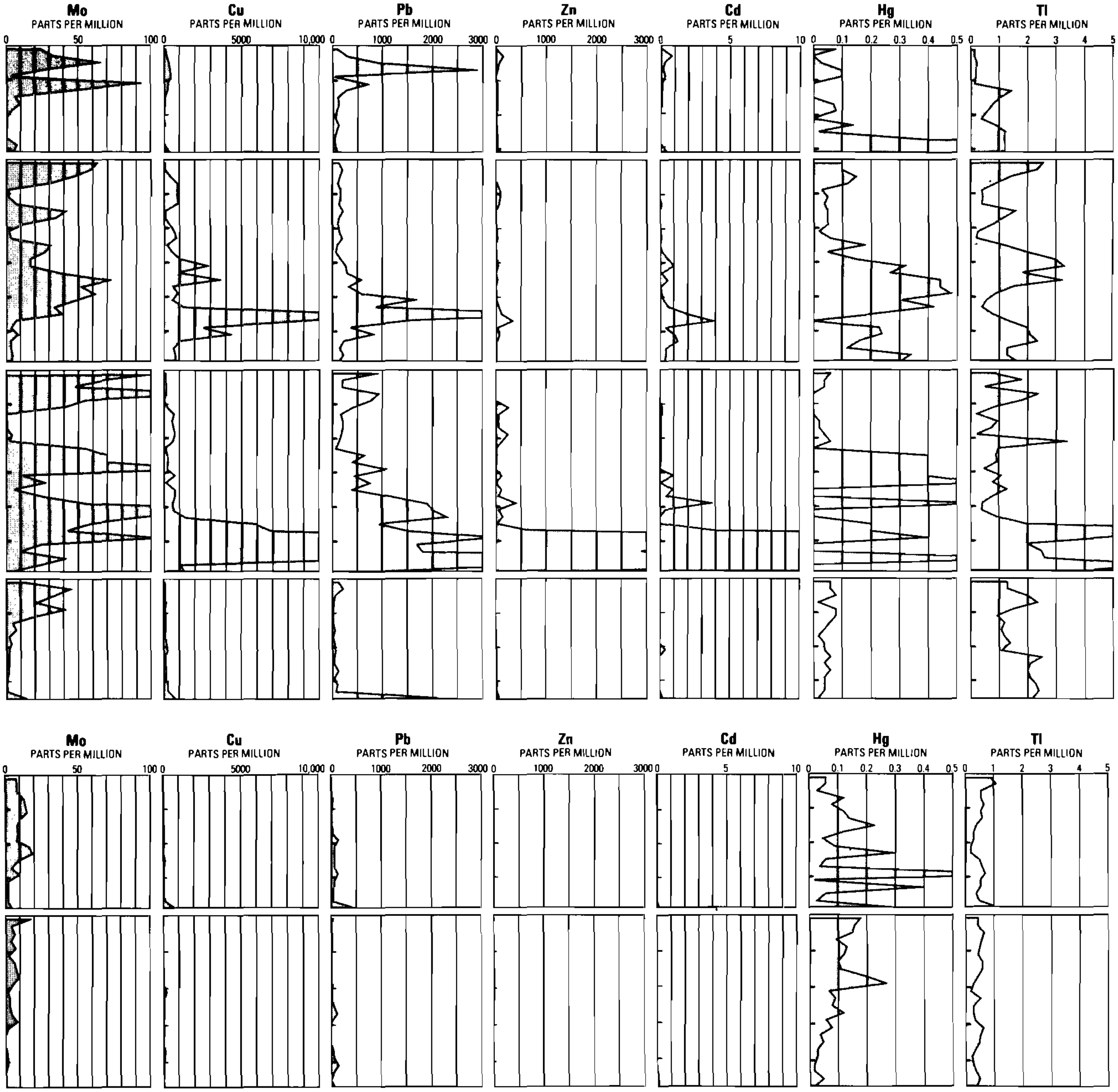


Figure 4 (continued).

Mo. There is also a narrow zone of high Pb values, but Cu and Zn values are low overall. The low Cu and Zn values may be a result of oxidation of Cu and Zn sulfides, because most of the samples from BHR 77 are from the oxidized zone. Tl and Hg contents of some samples from below the high-Au zone are higher than those within it, suggesting either a Hg or Tl halo or depletion in the oxidized zone. Neither Hg nor Tl haloes are seen in the other drill holes, and no consistent association of Tl with other elements was identified clearly in the geochemical profiles.

Au is associated with Ag and Te in all of the drill-hole profiles from the main pit area and Rainsford South, except for BHR 61, where the Te values are low. This Au-Ag-Te association plots as a broad linear zone on scatter graphs and is consistent with results of scanning-electron microscope and microprobe studies (Gunter and Padgett, 1988; Clark and others, 1992; Back and Clark, 1993). Geochemical profiles from drill holes in the main pit area (BHR 77, 61, 40, and 29) generally show close similarities in distributions of Bi, Sb, As and Mo that are, in turn, similar in a broad sense to the Au and Ag distribution. Cu, Pb and Zn are a third group of elements that behave similarly in drill holes from the main pit area. There is a broad similarity between the distributions of Cu-Pb-Zn and Ag-Te-Bi-Sb-As-Mo, but not between Cu-Pb-Zn and Au. The distribution of Cd is very similar to that of Zn, which would be expected because Cd commonly substitutes for Zn in sphalerite.

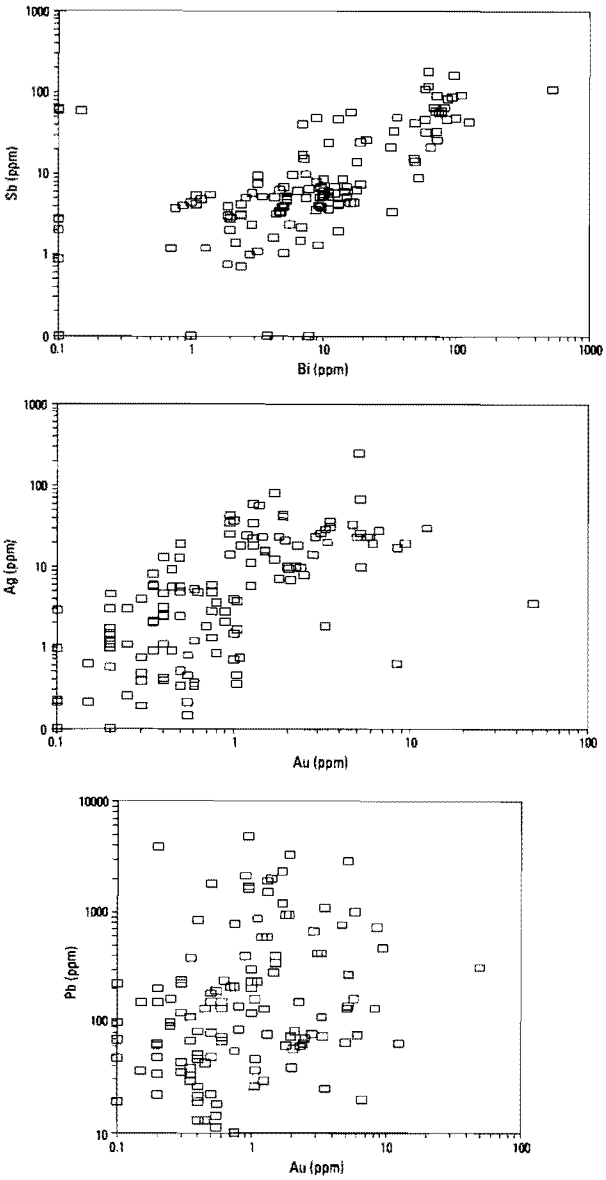


Figure 5. Examples of xy (scatter) graphs of element pairs plotted on logarithmic scales showing linear zones (Bi-Sb), broad linear zones (Au-Ag), and widely scattered data with little or no apparent relation (Au-Pb).

Discussion and conclusions

Field relations and petrographic studies indicate a complex history of mineralization and tectonism, which have caused overprinting of mineral assemblages at Barite Hill. Overprinting of mineral assemblages and weathering are reflected by variations in the geochemical profiles. Rainsford South differs from the main pit area in the absence of quartz-barite rock, in the presence of narrower mineralized zones and in a greater divergence of mineralized zones from lithologic trends (Figure 3). Geochemical profiles from Rainsford South differ from those in the main pit area in that zones of elevated Au-Ag-Te values are not accompanied by increased amounts of other elements in the Rainsford South area. The differences in geochemical profiles between the main pit area and Rainsford South suggest that the Au-Ag-Te association is separate and distinct from the other elements studied.

Scatter graphs for element pairs and geochemical profiles from the main pit area suggest that (1) distributions of Bi, Sb, As and Mo are similar to each other and broadly similar to that of Au, Ag and Te and (2) distributions of Cu, Pb and Zn generally are similar to each other and to those of Ag, Te, Bi, Sb, As and Mo, but have little or no similarity to Au distribution. The chemical associations reflect the mineralogical associations, in which Ag and Au occur in their native states and in electrum and tellurides. The mineral associations of Ag are more complex than those of Au and include complex selenides and galena, accounting for the apparent association of Ag with many of the elements in chemical profiles and scatter graphs. Differences in the distributions of Cu, Pb and Zn from those of Au, Ag, Te, Bi, Sb, As and Mo could be the result of differences in primary distribution, overprinting of successive generations of mineral assemblages, removal of sulfides during weathering or a combination of factors. Zones containing high Zn values are narrower than those containing high Cu-Pb concentrations. Zn and Cd show a high degree of geochemical similarity. These geochemical associations, along with the identification of corresponding base-metal sulfide minerals, suggest that Zn and Cd are contained primarily in sulfides, which may be removed near the surface by weathering. Cu and Pb occur in both sulfides and complex selenides and tellurides. The differences between Cu-Pb and Zn mineralogy could account for high Cu and Pb zones being wider than high Zn zones, by reflecting differences in either primary distribution or response to weathering.

The geochemical distribution patterns of Barite Hill reflect both the effects of weathering and the primary distribution of elements. Elements that persist to the surface include Au, Ag, Bi, Sb, As and Mo. Weathering has resulted in oxidation, mobility, and a variable but generally strong depletion of some elements, especially Cu, Pb, Zn, Cd and Hg, and sometimes Ag, Te and Tl. Primary distribution patterns can be interpreted as reflecting overprinting of the following previously identified stages of mineralization: (1) base-metal-rich stage, (2) gold-poor (generally 0.3 to 1.0 ppm Au), base-metal-rich stage and (3) gold-rich (generally greater than 1.0 ppm Au), base-metal-poor stage. Only the gold-rich, base-metal-poor stage of mineralization is present at Rainsford South (Padgett and Watkins, 1988). The occurrence of only the Au-Ag-Te suite of elements at Rainsford South suggests that the gold-rich, base-metal-poor stage of mineralization is characterized by a Au-Ag-Te association. The Ag-Te-Bi-Sb-As-Mo-Cu-Pb-Zn-Cd association could reflect the gold-poor, base-metal-rich stage of Au mineralization; whereas, the Cu-Pb-Zn-Cd association reflects a base-metal-rich, sulfide-rich mineral assemblage.

Acknowledgements

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Table 1. Results of chemical analyses of samples from six reverse-circulation drill holes at Barite Hill, South Carolina. Results that were below the limit of determination are reported as zero. All concentrations are in parts per million. Analyses for Au by graphite furnace atomic absorption spectrometry (AAS); analyses for Te and Tl by flame AAS; analyses for Hg by cold-vapor AAS; analyses for Ag, As, Bi, Cd, Cu, Mo, Pb, Sb and Zn by inductively coupled plasma-atomic emission spectrometry (ICP-AES). AAS analyses by B.H. Roushey, P.L. Hageman and F. Tippitt; and ICP-AES analyses by J.M. Motooka in the U.S. Geological Survey laboratories in Denver, Colorado.

Main pit area

Depth in feet	Ag	As	Au	Bi	Cd	Cu	Hg	Mo	Pb	Sb	Te	Tl	Zn
BHR 77													
0-5	1.8	170	3.3	19	0.11	140	0.08	24	110	24	73	0.15	23
5-10	3.5	200	49.5	60	0.8	220	0	33	310	32	123	0.15	150
10-15	23	220	5.9	100	0.31	330	0.03	66	1000	48	170	0.25	63
15-20	68	600	5.2	78	0.15	430	0.1	30	2900	59	161	0.2	43
20-25	23	390	5	34	0.32	490	0.1	4.7	65	33	114	0.2	0.16
25-30	17	420	8.5	96	0.14	300	0	94	730	160	155	0.15	34
30-35	10	80	5.25	21	0.11	250	0	49	270	26	7.95	1.45	38
35-40	0.92	54	0.35	2.4	0.073	80	0	6.9	110	4.1	13.2	1.05	30
40-45	5.7	91	1.25	7.4	0.1	89	0.07	9.7	130	9.8	7.85	0.8	37
45-50	3.6	61	0.8	4.7	0	55	0.08	4.1	84	6.3	3.3	0.6	17
50-55	0.57	12	0.2	0.71	0	43	0	0.9	62	1.2	55	0.4	18
55-60	0.62	9.9	8.35	6.7	0	110	0.14	1.1	130	1.5	3.6	0.9	25
60-65	0.25	5.7	0.25	0	0	31	0.02	0,52	90	0	6.6	1.25	22
65-70	0	5.1	0.1	0	0	29	0.38	1.1	47	0	6.45	1.2	46
70-75	1.2	7.8	0.2	2.4	0.023	130	2.3	7.9	63	0.72	8.5	1.25	38
75-80	2.85	7.7	0.1	5	0.375	390	2.5	5.7	99	1.045	8.125	1.25	96.5
BHR 61													
0-5	0.83	240	0.8	72	0	120	0.1	63	140	90	9.5	2.55	1.9
5-10	1.3	240	0.75	110	0	130	0.1	59	210	92	5	2.35	1.3
10-15	1.65	235	1.05	125	0	470	0.15	48	160	42.5	5.65	1.425	2.25
15-20	0.71	210	1	49	0	910	0.12	31	120	14	6	0.9	34
20-25	0.074	39	0.032	5.3	0	930	0.03	2.1	180	4.8	0.3	0.4	85
25-30	0.076	38	0.018	5.3	0	930	0.05	2	180	5.2	0.1	0.45	89
30-35	0.21	35	0.15	2.9	0.15	940	0.04	7.6	150	5.8	0.3	0.4	78
35-40	3.9	180	1	7.5	0.029	140	0.05	42	230	4.9	1.8	1.6	8.2
40-45	0.33	210	0.5	5.6	0.036	140	0.05	35	150	2.3	1.35	1.2	5.4
45-50	0.19	50	0.3	2	0.053	400	0.05	12	120	2.9	2.3	0.8	12
50-55	0	24	0.022	0.87	0.073	660	0.02	2	150	4	0.35	0.25	21
55-60	0	47	0.2	1.4	0.12	810	0.06	3.5	200	5.5	0.9	0.2	38
60-65	1.1	34	0.25	2	0.038	260	0.18	31	99	2	1	1.2	8.6
65-70	2.4	62	0.5	6.4	0.19	570	0.05	27	79	6.1	2.1	2	15
70-75	5.6	83	0.5	5	0.6	1100	0.15	17	180	6.8	2.6	3	38
75-80	23	82	1.45	7.8	0.99	2900	0.32	17	280	0	1.4	3.3	49
80-85	37	130	1	4.3	0.14	1000	0.27	39	300	5.1	1.35	1.85	9.6
85-90	24	160	1.2	7.1	0.57	3700	0.44	73	590	15	1.2	3.25	42
90-95	15	110	1.5	8.9	0.096	610	0.44	53	340	7.9	0.6	1.55	9.6
95-100	22	180	1.3	8.8	0.17	930	0.48	62	590	48	0.85	0.9	25
100-105	14	170	0.95	13	0.28	580	0.31	49	1700	47	11	0.55	25
105-110	18	220	1.1	7	0.68	1300	0.42	34	880	40	2.75	0.4	74
110-115*	43	180	0.95	16	2	14000	0.22	39	4800	56	2.7	0.75	130
115-120	35	370	0.95	59	3.9	9200	0	7.3	1600	110	9.4	1.35	350
120-125	5.8	59	0.35	7	0.5	2600	0.23	4.1	380	17	5.8	2	49
125-130	13	110	0.4	11	1.1	4400	0.24	8.6	840	24	5.2	2.1	88
130-135	4.85	37	0.625	5.9	1.3	1100	0.16	3.6	235	9.6	10.3	2.375	39.5
135-140	3	31	0.25	3.2	0.46	660	0.12	3.7	160	7.4	4.4	1.3	34
140-145	3.9	38	0.3	3.2	0.47	790	0.34	4.8	240	9.2	5	1.3	39
145-150	3	22	0.2	3.5	0.33	810	0.31	3.6	150	5.2	9.3	1.65	44

*Copper exceeded the upper limit

Table 1 (continued).

Depth in feet	Ag	As	Au	Bi	Cd	Cu	Hg	Mo	Pb	Sb	Te	Tl	Zn
							BHR 40						
0-5	1.8	280	0.02	48	0	120	0.06	110	920	15	21	0.8	3.7
5-10	1.8	120	0.7	9.7	0	160	0.04	70	210	3.8	10	1.8	11
10-15	1.5	150	1	15	0	190	0.04	48	200	6.9	15	0.5	10
15-20	7	340	1.8	64	0	140	0	150	930	21	13	2.4	4.7
20-25	6	110	0.75	52	0	38	0	55	780	8.7	7.6	1.8	3.2
25-30	2.1	79	0.9	19	0.166	250	0	41	400	7.4	15	0.85	260
30-35	0.96	19	0.05	2.4	0.17	660	0	0.38	180	3.1	0.95	0.25	72
35-40	0.38	20	0.3	1.9	0.083	550	0.02	1.3	220	3	13	0.95	63
40-45	0.22	16	0	2	0.073	650	0.02	0.71	220	2.8	6.7	0.75	70
45-50	0.79	34	0.55	11	0.096	730	0.04	4.4	190	3.6	28	0.25	250
50-55	0.36	27	0.6	2.9	0.13	600	0.06	2.8	150	2.3	7	3.4	130
55-60	6.8	90	2.1	18	0.078	130	0	55	82	14	13	1	16
60-65	23.5	440	2.9	94	0.103	230	0.4	70	660	87	40.5	0.9	20
65-70	26	410	3.1	68	0.069	290	0.4	70	420	65	32	0.95	16
70-75	36	660	3.5	85	0.034	230	0.4	140	1100	47	97	0.5	14
75-80	19	330	9.4	71	0.99	740	0.4	12	470	33	22	1.1	130
80-85	33	220	4.7	70	0.07	150	0.6	28	770	58	24	0.8	19
85-90	29	310	3.3	49	0.95	740	0	6.4	420	42	25	1.3	120
90-95	12	750	1.7	36	0.52	720	0	26	1200	49	64	0.8	71
95-100	59	690	1.3	58	3.8	590	0.6	57	1900	46	32	0.45	420
100-105	56	900	1.4	87	0.42	620	0	200	2000	83	77	0.4	65
105-110	81	1100	1.7	74	0	1400	0	95	2300	56	9.4	0.9	140
110-115	44	640	1.9	82	0	5800	0.2	59	940	65	22	1.9	33
115-120	34	370	1.3	0	4.1	6900	0.2	43	1500	62	59	10	670
120-125	42	710	1.9	530	61	24000	0.4	110	3300	110	39	5	13000
125-130	25	1000	0.95	62	33	24000	0	25	1700	120	8.6	2	6800
130-135	19	1000	0.5	62	16	20000	0	11	1800	180	1000	2.5	2900
135-140	13	280	0.5	0	45	16000	0.8	42	11000	60	1000	2.6	10000
140-145	4.6	73	0.2	0	29	1100	0	24	3900	0	63	7	5900
145-150	0	55	0.05	0	20	1300	0.08	4.8	1100	0	6	4.1	1800
							BHR 29						
0-5	0.33	64	0.6	11	0	68	0.06	13	130	5.3	8	1.3	2.6
5-10	0.74	370	1.1	32	0	140	0.06	45	230	21	45	1.3	4.6
10-15	1.2	100	0.6	11	0	110	0.08	34	66	5.2	17	2	5.7
15-20	0.9	44	0.45	6.85	0	190	0.02	22	42	2.15	18	2.35	7.55
20-25	5.9	76	0.35	17	0	130	0.08	42	38	4.4	11	1.5	5.6
25-30	8.1	82	0.35	13	0	150	0.08	22	29	4.2	12	0.95	13
30-35	1.7	67	0.2	9.2	0	180	0.06	5	34	4	11	1.2	21
35-40	0.96	61	0.1	4.8	0	120	0.04	7.1	69	3.4	11	1.1	13
40-45	0.62	25	0.15	2.2	0	160	0.02	2.5	36	1.4	3.8	1.2	16
45-50	2	44	0.35	4.7	0.039	200	0.04	4	67	3.4	9.3	1.4	20
50-55	5.3	97	0.6	10	0.42	270	0.04	2.4	72	6.1	25	1.1	35
55-60	4.8	65	0.5	5.3	0	130	0.06	2.1	48	4.7	19	2.5	19
60-65	2.5	59	0.4	4.9	0	170	0.04	1.6	46	3.8	13	2.1	23
65-70	9.1	120	0.45	10	0	220	0.06	2.3	130	5.6	20	2	34
70-75	2.4	55	0.4	5.1	0	150	0.04	1.1	50	3.9	9.6	2.1	24
75-80	2.1	54	0.35	9.7	0	310	0.04	0.81	110	6.6	12	2.3	30
80-85	1.1	12	0.4	2.8	0.035	300	0.04	1.3	81	1	6.3	2.4	22
85-90	2.8	940	0.9	0.15	0.23	790	0.02	14	2100	58	200	2.2	68
							Rainsford South						
							BHR 20						
0-5	0.27	35	0.06	4.4	0	23	0.06	7.8	17	3.2	12.6	0.9	1.4
5-10	0.18	50	0.06	8.8	0	30	0.06	8.5	35	3.5	15.9	1.1	3.3
10-15	0.21	41	0.1	4.8	0	39	0.03	8.5	19	3.3	9.8	0.55	5.1
15-20	0.76	94	0.3	9.7	0	59	0.12	13	43	6.7	20.4	0.55	4.4
20-25	0.48	87	0.3	11	0	62	0.08	14	35	6	20	0.65	4.6
25-30	0.42	81	0.4	12	0	62	0.12	15	19	5.8	20	0.55	4.7
30-35	3.1	66	0.4	9.4	0	89	0.14	9.9	26	5	16	0.6	7.9
35-40	11	87	1.25	7.8	0	120	0.23	8.3	29	6.4	29	0.4	8.3

Table 1 (continued).

Depth in feet	Ag	As	Au	Bi	Cd	Cu	Hg	Mo	Pb	Sb	Te	Tl	Zn
							BHR 20						
40-45	10	88	2	10	0	120	0.12	9.3	39	8.5	40	0.3	13
45-50	10	120	2.25	12	0	110	0.05	8.2	150	6.9	63	0.3	12
50-55	21	93	1.95	9.9	0	77	0.09	17	74	5.3	28	0.2	11
55-60	18	83	2.3	13	0	65	0.3	19	60	4.3	34	0.2	7.2
60-65	14	89	2.8	15	0	150	0.06	9.1	77	5.2	58	0.5	9.2
65-70	20	49	3.4	13	0	110	0.04	4.7	74	1.9	145	0.6	7.3
70-75	26	97	5.2	18	0	110	0.8	10	140	6.2	200	0.7	6.1
75-80	19	65	6.1	14.5	0	125	0.02	2.6	76.5	5.95	135.5	0.55	9.4
80-85	30	33	12.4	33	0	80	0.4	2.1	63	3.4	95	0.55	7.7
85-90	3.7	40	1.05	16	0	100	0.06	2.2	46	4.4	24	0.4	11
90-95	2.8	81	0.75	14	0.041	210	0.03	2.4	54	8.6	32	0.5	24
95-100	16	280	1.5	72	0.16	730	0.3	4.7	400	26	122	1.05	18
							BHR 23						
0-5	0	34	0.2	2.4	0	51	0.18	18	48	3	7.8	0.45	24
5-10	0.45	43	0.55	1.1	0	34	0.16	4.5	18	4.2	10.1	0.45	1.5
10-15	0.45	58	1.05	0.77	0	39	0.15	6.9	36	3.7	22	0.65	2.5
15-20	0.145	31	0.55	0	0	39	0.095	3.95	11	2.75	7.525	0.575	2.6
20-25	0.35	46	1.05	1	0	21	0.13	7.4	26	4.4	15.5	0.5	1.7
25-30	0.21	29	0.55	0	0	19	0.12	2.4	14	2.8	7.8	0.45	3.5
30-35	0.51	41	0.5	1.1	0	28	0.1	6.5	22	5.4	14.5	0.6	2.1
35-40	0.39	36	0.4	1.2	0	23	0.11	7.9	21	4.8	8.4	0.6	3.8
40-45	4.6	19	0.4	0	0	27	0.2	9.4	13	0.89	7.3	0.45	5.6
45-50	2	25	0.35	0	0	62	0.27	5.4	33	2	5.8	0.3	17
50-55	1.5	15	0.2	0	0	220	0.07	2.3	22	0	5.35	0.2	12
55-60	31	19	3.5	1.3	0.056	96	0.09	3.6	25	1.2	45	0.55	7.1
60-65	23	20	1.8	1.9	0.047	57	0.08	3.6	61	3.9	32	0.3	6.9
65-70	250	23	5.1	2.6	0.033	81	0.12	4.8	130	5	210	0.3	11
70-75	28	22	6.6	0	0	41	0.06	8.7	20	0	48	0.35	6.1
75-80	4.8	9.1	0.75	0	0	82	0.08	2	10	0	6.5	0.65	3.1
80-85	1.1	4.3	0.2	0	0	60	0.04	0.59	6.5	0	4.9	0.55	4.1
85-90	0.98	5.1	0.2	0	0.022	47	0.05	0.4	6.1	0	4.3	0.5	8.3
90-95	9.4	25	2.05	4.2	0.051	160	0.03	1.6	57	1.6	40	0.35	11
95-100	7.9	21	2.5	3.2	0	110	0.03	2	70	1.1	75	0.25	13
100-105	23	19	5.7	9.1	0	75	0.02	2	160	1.3	140	0.3	8
105-110	9.6	22	2.4	3.8	0.042	69	0.02	0.95	63	0	33	0.4	11
110-115	5.6	25	0.45	1	0.069	39	0.05	0.72	13	0	7.6	0.5	16
115-120	18	13	1.3	1.9	0.13	70	0.02	0.6	77	0.76	35	0.4	26

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PRELIMINARY RESULTS OF PETROGRAPHIC STUDIES OF THE BARITE HILL GOLD DEPOSIT IN THE SOUTHERN CAROLINA SLATE BELT, SOUTH CAROLINA

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Abstract

A petrographic study of the Barite Hill deposit, one of four active gold mines in the Carolina slate belt, was done on three unoxidized samples from gold-rich zones by use of optical and scanning electron microscope techniques. Au-Ag-Te (sylvanite?) was found to be the principal gold mineral, although electrum (Au-Ag) was detected in one sample. In mineralized fragmental volcanic rock, where the host rock is best preserved, precious and most base-metal minerals are associated with pyrite, which occurs in relict felsic volcanic fragments and quartz-pyrite veins. In quartz-pyrite-rich rock, where the host rock has been disrupted by pyrite-muscovite and quartz-rich bands, gold also occurs as Au-Ag-Te, but predominantly within and interstitial to late-stage coarse-grained quartz. In barite-rich rock, late stage barite has largely replaced quartz-pyrite veins;, and no relict host rock remains. In the sample from this rock, base-metal minerals and gold (as Au-Ag-Te) occur along boundaries between pyrite grains in the quartz-pyrite matrix; neither gold nor base-metal minerals were observed in barite. Thus, gold in the gold-rich zones at Barite Hill apparently was concentrated initially as Au-Ag-Te and electrum in pyrite and then partially reconcentrated in late-stage quartz, but was not remobilized by the introduction of late-stage barite. Base-metal sulfide minerals apparently postdate pyrite and predate late-stage quartz and barite.

Introduction

Petrographic studies of samples of diamond drill core from the Barite Hill gold deposit have been initiated for the purpose of defining the mineralogic characteristics of the deposit and providing information about the relationship of mineralization to regional geologic events and the origin of the deposit. The Barite Hill deposit, which began production early in 1991, is the southernmost of four active gold mines in the Carolina slate belt; the other mines are the Ridgeway, Haile and Brewer, to the northeast in South Carolina (Figure 1). The Barite Hill deposit, which is in greenschist facies metamorphic rocks in the southern part of the Carolina slate belt, consists of two parts: the main pit area and the Rainsford South area (Figure 2).

The deposit is hosted by metavolcanic and metasedimentary rocks that locally have been called the "felsic pyroclastic sequence" and correlated with the Persimmon Fork Formation to the northeast (Carpenter and others, 1982). The felsic pyroclastic sequence generally is considered to be comagmatic with the Early Cambrian Lincolnton metadacite (Carpenter and others, 1982; Gunter and Padgett, 1988). Three stages of mineralization have been identified: (1) local base-metal sulfide having no anomalous gold, (2) early, gold-poor mineralization (generally 0.3 to 1.0 ppm Au) having abundant pyrite and base-metal sulfides, and (3) late, gold-rich mineralization (generally greater than 1.0 ppm Au) having sparse base-metal sulfides. Gold commonly occurs in quartz-pyrite veins that cut across lithic fragments, which are chiefly volcanic, and in replacement material that forms the matrix of fragmental rocks. Host rock is obliterated in intensely sheared and altered rocks that consist mainly or entirely of quartz and pyrite, with or without barite. Ore minerals are listed in Table 1.

Three unoxidized, gold-rich samples were selected for detailed study, which combined optical and scanning electron microscope (SEM) methods to determine the distribution of precious- and base-metal minerals and the mineralogic and textural associations. These studies revealed that many different ore minerals and suites of minerals are present, some of which are very fine grained. Identification of fine-grained minerals was based primarily on qualitative energy-dispersive X-ray analyses (EDX) as part of the SEM study, and, therefore, is tentative.

The samples were selected to represent three common textures observed in the drill core from gold-

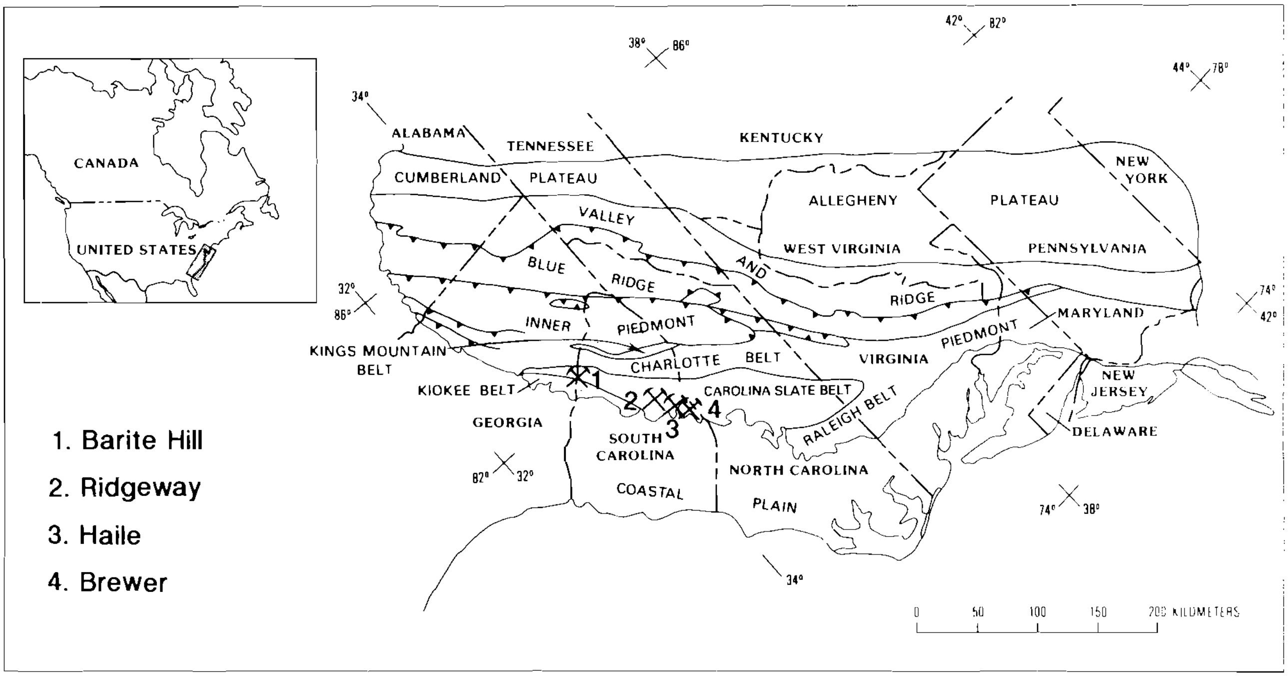


Figure 1. Generalized map of the Appalachian region illustrating the major provinces, thrust sheets, and locations of active gold mines in the Carolina slate belt. Modified from Price and Hatcher (1983).

rich zones. One sample from the main pit area has a fragmental texture, wherein quartz and pyrite have replaced the matrix between igneous fragments. The second sample is a quartz-pyrite-rich rock from the Rainsford South area in which host-rock fragments generally are obscured by well-developed foliation and crosscut by veinlets of pyrite and later-stage quartz. In the Rainsford South area, barite is rare and the only stage of mineralization that has been recognized is the late, gold-rich stage. The third sample is from a zone of intense quartz-barite replacement of the host rock in the main pit area. The sample consists mainly of coarse-grained, partially aligned barite blades, with lesser amounts of quartz and pyrite.

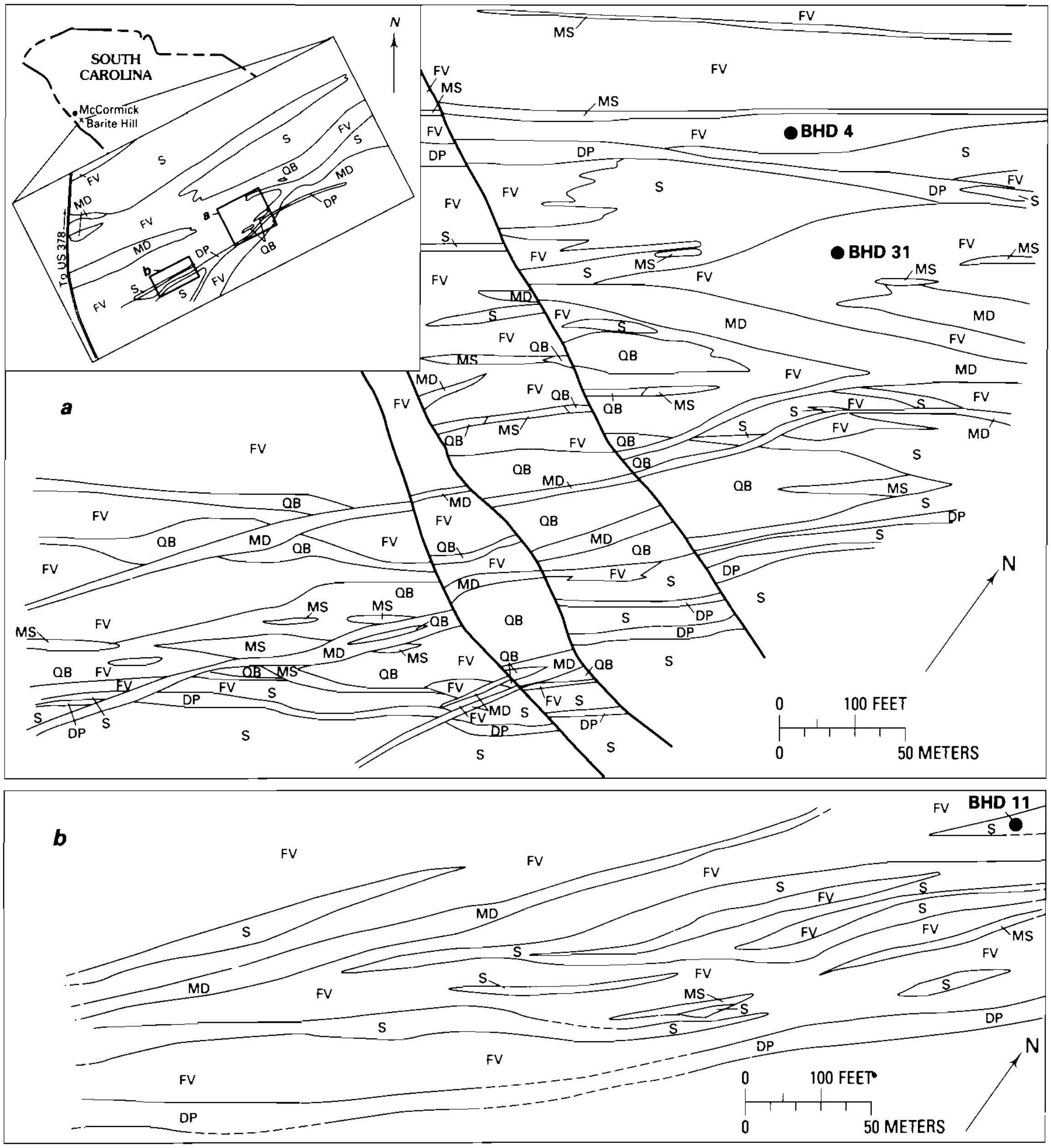
Petrographic descriptions

Mineralized fragmental rock

Unoxidized fragmental rock was collected from a depth of 155 feet in drill hole BHD 4, which is located in the northern part of the main pit area (Figure 2). Assays of the 150- to 155-foot interval of core, by Skyline Labs, Inc., for Amselco Exploration, Inc., indicate that the sample is from a high Au (8.7 ppm) and Ag (14.2 ppm) section of the core that also contains relatively high concentrations of Cu (2,500 ppm), Zn (1,160 ppm) and Pb (610 ppm).

The sample consists of metamorphosed felsic, fragmental, volcanic rock partly replaced by quartz-pyrite veins and broken by subsequent shearing (Figure 3). The sample is dominated by a single dacitic fragment that contains embayed quartz phenocrysts (as much as 2.5 mm in diameter) and pseudomorphs after hornblende phenocrysts (as much as 2 mm long) that now consist of aggregates of fine-grained muscovite with minor amounts of quartz and pyrite. The groundmass of this and other fragments is recrystallized and consists of granular quartz (grains are about 60 µm in diameter) containing disseminated, rounded pyrite grains and, locally, muscovite. Late-stage, coarse-grained quartz-pyrite veins cut this rock. Quartz in the veins locally forms curved pressure fringes around pyrite grains, indicating that pyrite grains rotated while the quartz fringes were forming; quartz pressure fringes are syntectonic. Some quartz-pyrite veins bordering

Figure 2. Geologic maps of the (a) main pit and (b) Rainsford South areas of the Barite Hill deposit. All of the lithologies indicated on the maps are within the felsic pyroclastic unit. Mine maps modified from Padgett and Watkins (1988); location map modified from Gunter (1986).



EXPLANATION

- QB — Quartz-barite rock
- MS — Sulfide-rich rock. Gossan in oxidized zone, massive sulfide where unoxidized
- MD — Mafic to intermediate metatuff, dike, or sill. Massive to weakly foliated
- DP — Feldspar metaporphyry. Massive to weakly foliated intrusive body of probable dacitic composition
- S — Metasedimentary rocks. Thinly bedded to finely laminated, medium- to fine-grained rocks interlayered with felsic crystal vitric tuff and medium- to coarse-grained, volcaniclastic sandstones to conglomerates
- FV — Felsic metavolcanic rocks. Fine-grained, sericitic metatuffs, commonly with quartz eyes; includes medium- to coarse-grained metatuffs and metatuff breccias
- Contact, dashed where indefinite
- High-angle fault
- ● Drill hole

Table 1. Ore mineralogy at Barite Hill, South Carolina (modified from Gunter and Padgett, 1988).

Gold	
Native gold	Au
Sylvanite	$(Au,Ag)Te_4$
Electrum	(Au, Ag)
Silver	
Native silver	Ag
Electrum	(Au,Ag)
Argentite	AgS
Galena	PbS
Hessite	Ag_2Te
Bismuth and copper selenides	
Tellurides	
Copper	
Chalcopyrite	$CuFeS_2$
Chalcocite	Cu_2S
Bornite	Cu_5FeS_4
Covellite	CuS
Goldfieldite?	$Cu_{10}Te_4S_{13}$
Tennantite?	$Cu_{12}As_4S_{13}$
Atacamite?	$Cu_2Cl(OH)_3$
Tellurides	
Lead	
Galena	PbS
Cosalite?	Pb_2Bi_2S
Plumbogummite?	$PbAl_3(PO_4)_2(OH)_5H_2O$
Zinc	
Sphalerite	(Zn,Fe)S
Molybdenum	
Molybdenite	MoS_2

the dacitic fragment are sheared, as indicated by strained, comminuted grains of quartz, and rounded and broken pieces of pyrite. Schistosity, defined by aligned muscovite grains, appears parallel to subparallel to shearing and to the quartz-pyrite veins.

Precious-metal minerals are associated with pyrite, which is ubiquitous in the section, and not with quartz. This association indicates that precious-metal mineralization occurred before late-stage quartz in quartz-pyrite veins and prior to shearing. Gold and silver were found to occur as electrum (Au-Ag) associated with Se-bearing galena and a Cu-Fe sulfide in a veinlet in pyrite within a quartz-pyrite vein (Figure 4a); as a Au-Ag-Cu-Se-Te inclusion in pyrite at the boundary between a sheared zone and a quartz-pyrite vein (Figure 4b); and as sylvanite(?) associated with a Cu-Zn sulfide (Au-Ag-Cu-Zn-Te-S±Fe) in a pyrite grain within the dacitic fragment (Figure 4c) Silver also occurs in Bi-Ag-Se±S grains in pyrite (Figure4b), and as Cu-Ag-Se-S (eucairite?) interstitial to pyrite grains in quartz-pyrite veins; silver-rich inclusions were observed in a Cu-Se-S grain in a quartz-pyrite vein.

Base metals occur chiefly as sulfide minerals in veins. In addition to Fe in pyrite, the four major metals in these minerals are Cu, Pb, Mo and Bi. Copper occurs in a variety of sulfide minerals. Cu-Fe-Te±As±Zn sulfosalts (goldfieldite?) occur as inclusions in pyrite grains in the dacitic lithic fragment and in quartz-pyrite veins (Figure 4b), adjacent to pyrite grains in sheared zones, and replacing pyrite in quartz-pyrite veins (Figure 4d). In Figure 4d, goldfieldite(?) cuts and encloses pyrite grains, but not quartz, indicating that the copper phase predates quartz in the vein. Minor amounts of Cu-Se-S and Cu-Cl (atacamite?) also were identified in quartz-pyrite veins (Figure 4d). Complex associations of Cu-Fe and Cu sulfides also occur as veins that cut relict felsic lithic fragments. Lead occurs predominantly in Se-bearing galena; minor plumbogummite(?) (Pb-Al-P) was observed in the dacitic fragment associated with a TiO_2 phase. Galena occurs as minor inclusions in copper-sulfide veins, in veinlets in pyrite within quartz-pyrite veins (Figure 4a), and as inclusions in pyrite in the dacitic fragment (Figure 4c). One molybdenite grain was observed within a crack in coarse-grained pyrite in a quartz-pyrite vein. Bismuth occurs as Bi-Ag-Se±S inclusions in pyrite (Figure 4b).

Quartz-pyrite-rich rock

Quartz-pyrite-rich rock, from the northeast corner of the Rainsford South area, was sampled from a depth of 171 feet from drill core BHD 11 (Figure 2). Assays of the 170- to 175-foot interval of core, by Skyline Labs, Inc., for Amselco Exploration, Inc., indicate that the sample is from a section of the core that is high in Au (1.5 ppm) and Ag (7.5 ppm) and relatively high in Cu (2050 ppm) and Ba (4700). Analyses by U.S. Geological Survey laboratories of a portion of the sample that was thin sectioned gave the following: 0.14 ppm Au (determined by flame atomic absorption spectroscopy, FAA; Norma Rait, analyst) and 17 ppm Ag and 750 ppm Cu (determined by inductively coupled plasma-atomic emission spectroscopy, ICP-AES; J M. Motooka, analyst). X-ray diffraction analyses of bulk core material (J. Hosterman, analyst) show that quartz constitutes about 65 percent; illite/muscovite, 20 percent; pyrite, 11 percent; and siderite, less than 1 percent of the sample.

The host rock of this banded quartz-pyrite-rich rock (Figure 5) apparently was a felsic volcanic rock with abundant quartz phenocrysts (about 0.5 to 1.0 mm), now rounded by dusty quartz overgrowths. The ground-

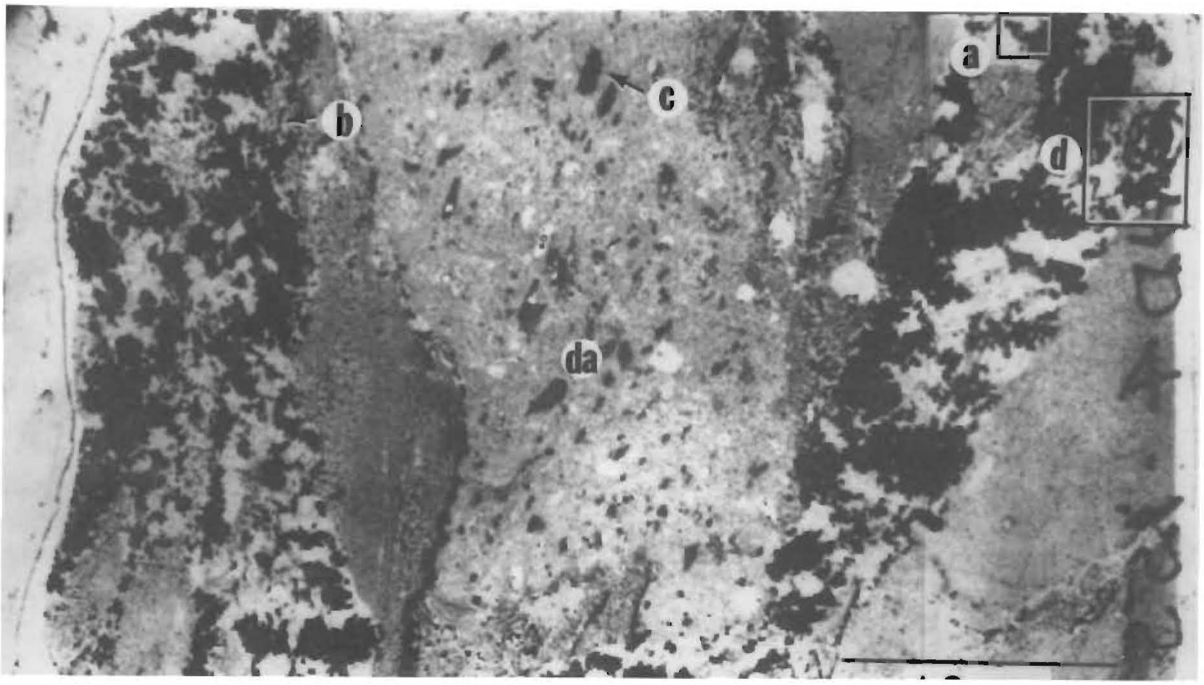


Figure 3. Photograph of thin section of mineralized fragmental rock illustrating a dacitic fragment (da) with sheared contacts with coarser quartz-pyrite veins (transmitted light). Areas a-d refer to locations of Figures 4a-4d, respectively.

mass has been recrystallized and consists predominantly of granular quartz with euhedral to rounded pyrite grains and fine-grained muscovite. Relicts of host rock are cut by pyrite-rich bands that include muscovite grains which cut the pyrite. Coarse-grained quartz (as much as 1 mm diameter) disrupts both the relict host rock and pyrite bands and forms pressure fringes adjacent to some of the pyrite grains. Muscovite foliation disrupts both relict host rock and pyrite bands, but not coarse-grained quartz, and is approximately parallel to banding in the rock. Thus, coarse-grained quartz is syntectonic, and muscovite foliation represents an earlier period of deformation than do the pressure fringes.

In the quartz-pyrite-rich rock analyzed, precious-metal minerals are associated primarily with quartz rather than with pyrite. Gold occurs (1) in and interstitial to coarse-grained quartz as Au-Ag-Te (sylvanite?) associated with Ag-Te (hessite?) (Figure 6a) and as Au-Ag-Te-Se; and (2) interstitial to pyrite as Au-Ag-Te (sylvanite?) associated with Ag-Te (hessite?) and Ag-Te-Se, and Cu-Ag-As±S±Se±Te±Zn±Ni (novakite?) that occurs at the boundary between quartz and pyrite grains (Figure 6b). Au-Ag-Te grains in Figure 6a are inhomogeneous. The larger grain is gold rich on one end (EDX spectrum shows Au, Ag and Te) and contains only Ag and Te (hessite?) at the other end. Although the textural relationship could not be determined, EDX suggests that the decrease in gold may be gradual from one end of the grain to the other. The close association of hessite(?) with sylvanite(?) suggests they are the result of decomposition of a third Au-Ag-Te phase and may not reflect the original conditions of gold and silver mineralization (Afifi and others, 1988). Gold was apparently concentrated with Ag and Te in this rock during a late tectonic event that caused formation of the quartz pressure fringes.

Metallic minerals in the quartz-pyrite-rich sample, with the exception of pyrite, are generally interstitial to pyrite in pyrite-rich bands and are not associated directly with quartz. Three metals predominate in this sample: Cu, Pb and Bi. Copper occurs primarily as a Cu-Fe-As-S±Te±Zn±Sb (tennantite?) interstitial to and partially replacing pyrite (Figure 6c). Lead occurs as Se±Te-bearing galena(?), Pb-Bi-S-Te±Se±Fe (cosalite?) (Figure 6d), and Bi-Pb-Te phases interstitial to pyrite.

Barite-rich rock

Barite-rich rock was sampled from a drill-core depth of 183.5 feet from drill hole BHD 31, which is located in

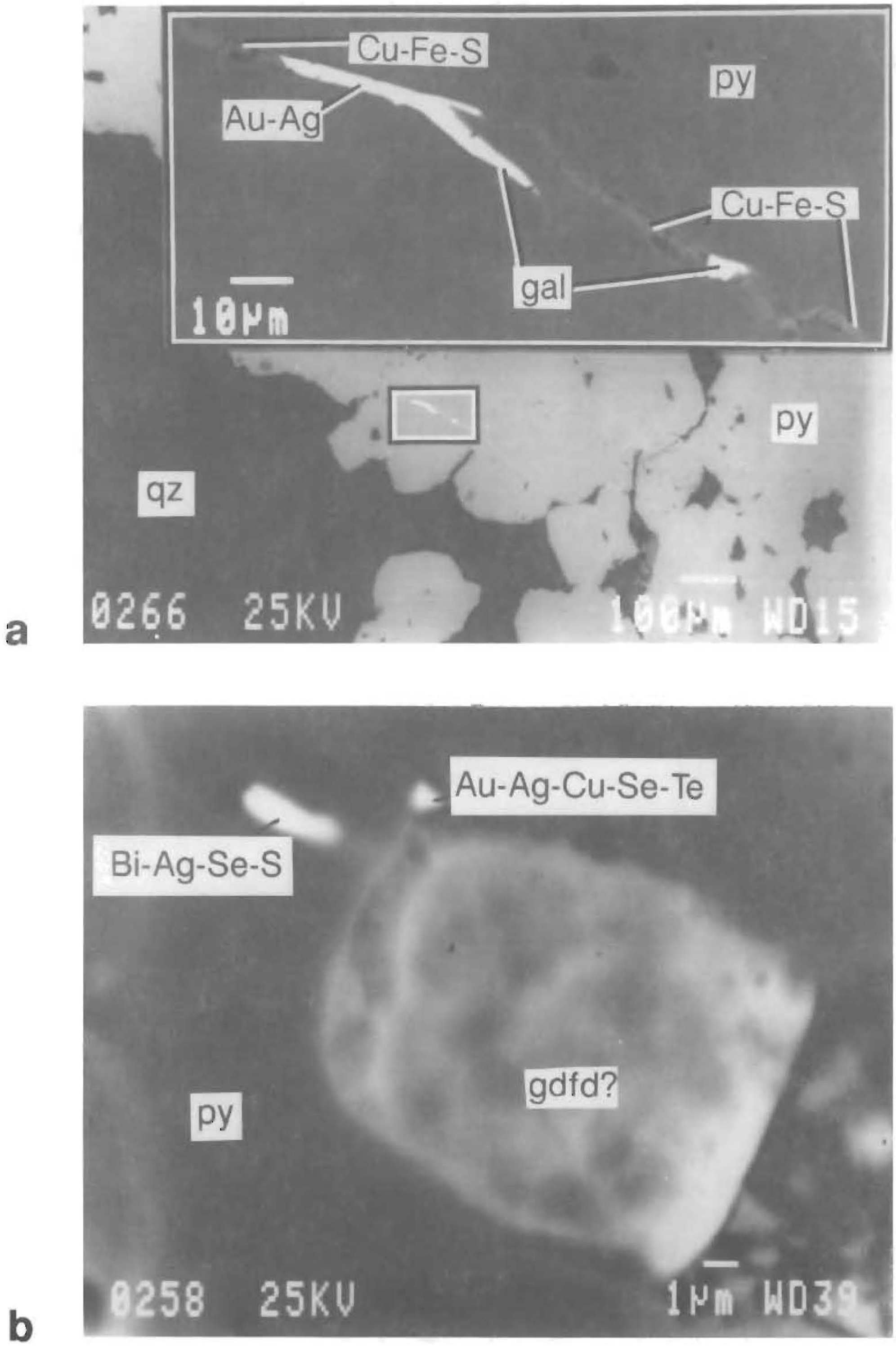
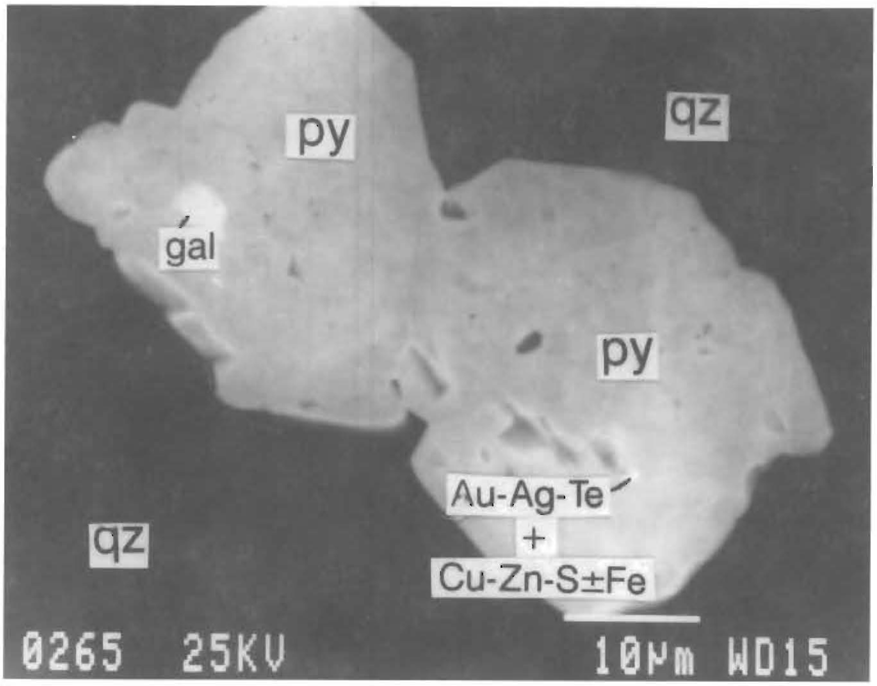


Figure 4. a) SEM backscattered electron image (BEI) of an electrum (Au-Ag)-galena (gal)-Cu-Fe sulfide (Cu-Fe-S) veinlet in pyrite (py) within a quartz (qz)-pyrite vein. Inset (top) shows enlarged view of veinlet (area a in Figure 3); b) SEM BEI of Au-Ag-Cu-Se-Te, Bi-Ag-Se-S and Cu-Fe-Te±As±Zn (goldfieldite?; gdfd?) inclusions in pyrite (py) at the boundary of a sheared zone with a quartz-pyrite vein (area b in Figure 3); c) SEM BEI of sylvanite(?) + Cu-Zn sulfide(?) (Au-Ag-Te + Cu-Zn-S±Fe)

c



d

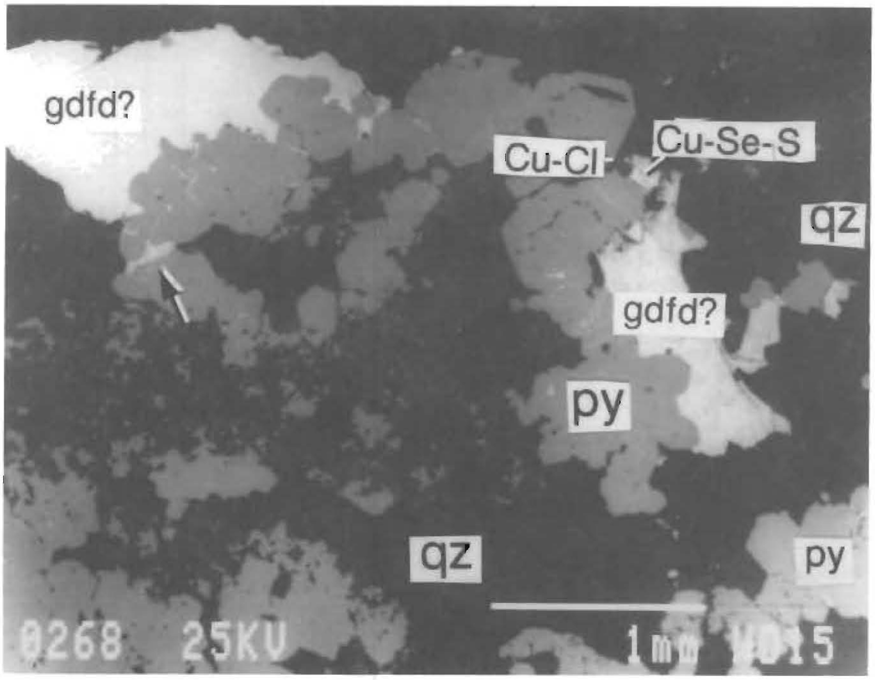


Figure 4 (continued). and galena (gal) inclusions in pyrite (py) grains within quartz (qz) (area c in Figure 3); d) SEM BEI of Cu-Fe-Te-S±As±Zn (goldfieldite?; gdfd?) replacing pyrite (py) in quartz (qz)-pyrite vein. Goldfieldite(?) veinlet (arrow) crosscuts pyrite but not quartz, suggesting that the Cu-bearing phase is younger than pyrite and older than quartz. Minor Cu-Se-S and atacamite(?) (Cu-Cl) associated with goldfieldite(?) (area d in Figure 3).

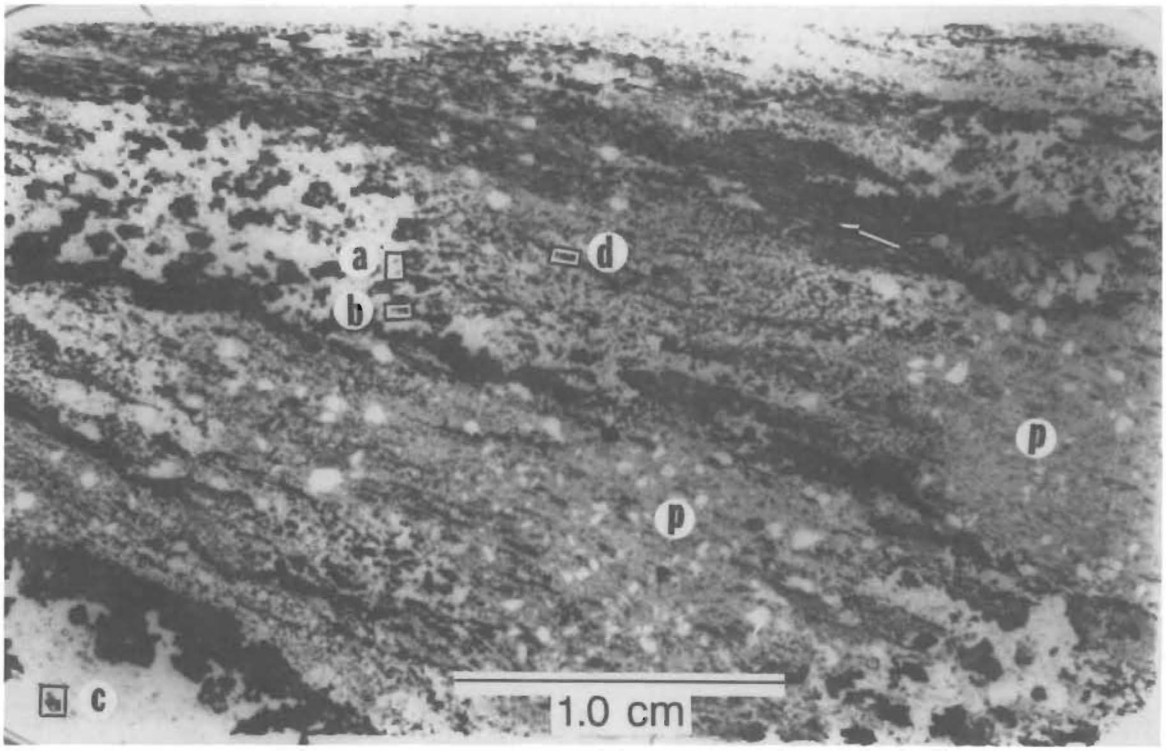


Figure 5. Photograph of thin section of quartz-pyrite-rich rock, illustrating protolith (p) cut by pyrite-rich bands (black) and coarse-grained quartz (white) transmitted light. Note aligned muscovite grains in pyrite (arrow), both of which define foliation in this sample. Areas a-d refer to locations of Figures 6a-6d, respectively.

the northeast part of the main pit area (Figure 2). Chemical analyses at U.S. Geological Survey laboratories, using FAA for Au (Norma Rait, analyst) and ICP-AES for Ag, Pb, Cu, and Zn (J.M. Motooka, analyst), for a portion of this sample gave the following: 0.53 ppm Au, 4.2 ppm Ag, 690 ppm Pb, 150 ppm Cu and greater than 1,900 ppm Zn.

The sample consists chiefly of large (up to about 2 cm long) partially aligned barite crystals that replace most of the matrix of granular quartz, muscovite and pyrite (Figure 7); no host rock remains. Muscovite crosscuts pyrite grains, as in the quartz-pyrite-rich sample, but the sample is foliated only weakly . Major phases are enclosed locally or enclosed partially by barite, indicating that barite was the last phase to form.

Base- and precious-metal minerals are interstitial to pyrite within the quartz-pyrite matrix in this sample. Gold and silver were detected in a grain of Au-Ag-Te (sylvanite?) that is located at the tip of a Bi-Te grain; silver also was detected in a grain of Bi-Pb-Ag-Te±S interstitial to pyrite. Base-metal minerals observed are interstitial to pyrite and include Se-bearing galena, Bi-Pb and Bi tellurides, molybdenite and sphalerite.

Discussion and conclusions

The three unoxidized samples from gold-rich zones at Barite Hill exhibit different degrees of destruction of host rock, different base-metal mineral associations, and different deformation and alteration characteristics. In the fragmental sample, where the host rock is best preserved, gold and silver occur in pyrite grains within the relict host rock as well as in pyrite within quartz-pyrite veins that cut and replace the host rock. The absence of gold in the late-stage, coarse-grained quartz indicates that gold and silver concentration occurred prior to the tectonic event that resulted in quartz pressure fringes adjacent to pyrite grains in the quartz-pyrite veins. In the quartz-pyrite-rich sample, the host rock has been disrupted by pyrite-rich bands, which in turn have been disrupted by coarse-grained quartz, some of which form pressure fringes adjacent to pyrite grains. Muscovite foliation disrupts both relict host rock and pyrite. Gold and silver occur predominantly in coarser grained quartz, suggesting that gold was remobilized locally during a tectonic event post-dating schistosity. In the barite-rich sample, which is dominated by coarse-grained barite, base- and precious-metal minerals occur interstitial to pyrite in the quartz-pyrite matrix and not in barite. Gold and silver are in Au-Ag-Te; silver is also in Bi-Pb-Ag-T±S. Thus, introduction of barite apparently did not cause remobilization of the base or precious metals.

Schistosity, represented by aligned muscovite grains that cut relict host rock and pyrite in the quartz-pyrite-rich rock, may have resulted from metamorphism and deformation during the early Paleozoic Delmar event, which is characterized by penetrative schistosity and tight isoclinal folds (Secor, 1987; Butler and Secor, 1991). Syntectonic quartz pressure fringes adjacent to pyrite postdate schistosity in the quartz-pyrite rock, suggesting that fringes formed during a later Alleghanian(?) event, which caused local mobilization of gold and silver. A later shearing event, indicated by the sheared quartz-pyrite veins in the fragmental ore, may represent an Alleghanian deformational event that occurred later than the event that caused formation of quartz pressure fringes. Study of additional samples is necessary to determine if these observations are consistent throughout the Barite Hill deposit.

Acknowledgments

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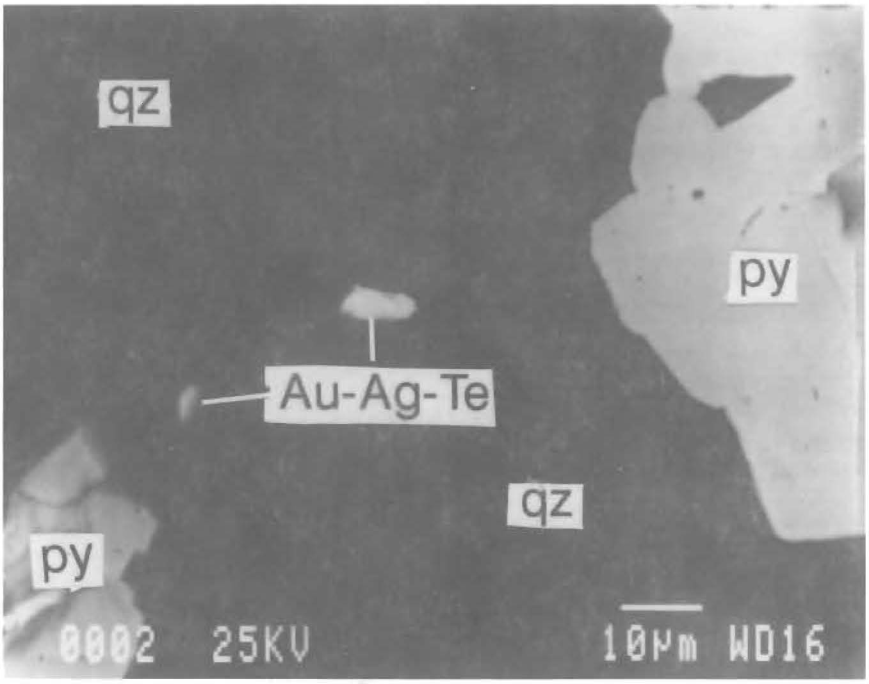

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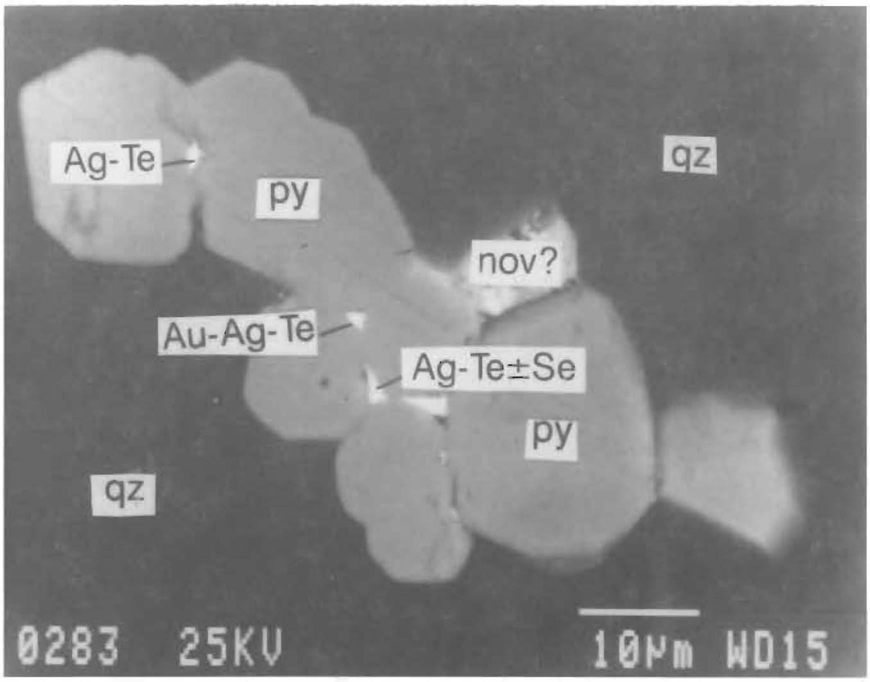

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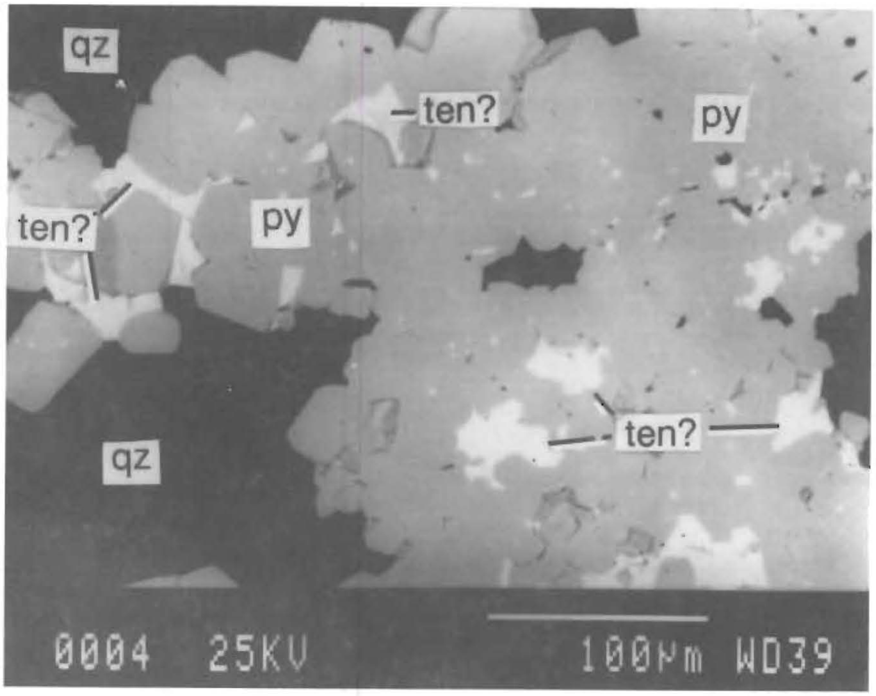
Figure 6. a) SEM BEI of gold in inhomogeneous sylvanite(?) (Au-Ag-Te) grains near pyrite (py) and interstitial to quartz (qz) (area a in Figure 5) The larger Au-Ag-Te grain has high concentrations of gold at one end of the grain; no gold was detected with EDX at the other end of the grain. Gold variation is apparently gradational across the grain; b) SEM BEI of gold and silver in sylvanite(?) (Au-Ag-Te) and silver in hessite(?) (Ag-Te±Se) interstitial to pyrite (py), and silver in Cu-Ag-As±S±Se±Te±Zn±Ni



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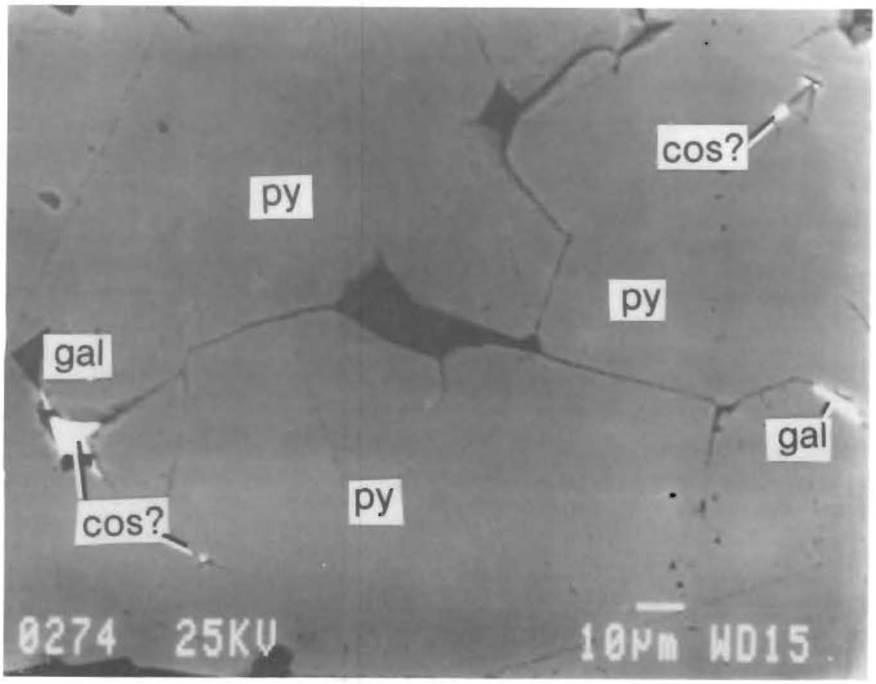

d

Figure 6 (continued). (novakite?, nov?) at the boundary between pyrite and quartz (qz) (area b in Figure 5); c) SEM BEI of Cu-Fe-As-S±Te±Zn±Sb (tennantite?, ten?) interstitial to and partially replacing pyrite (py) in quartz (qz)-rich area (area c in Figure 5); d) SEM BEI of Se±Te-bearing galena (gal) and Pb-Bi-S-Te±Se±Fe (cosalite?, cos?) interstitial to pyrite (py) (area d in Figure 5).

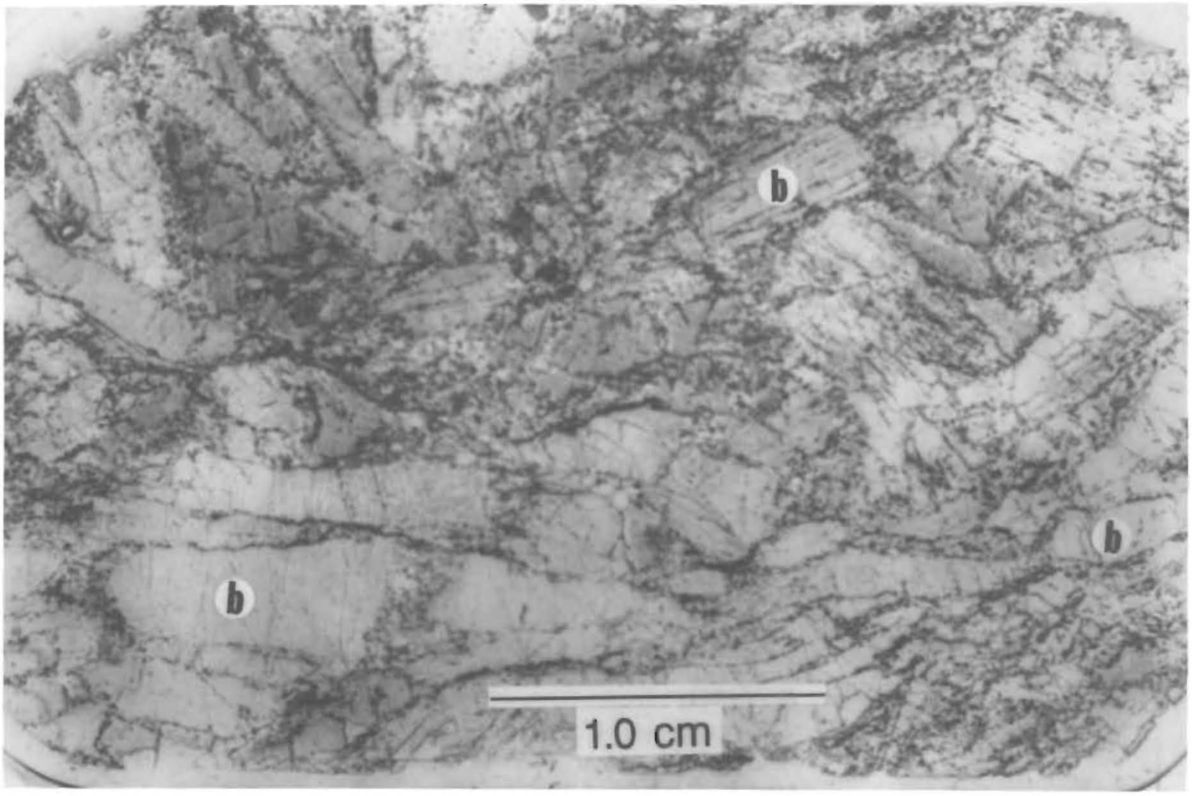

Figure 7. Photograph of thin section of barite-rich ore, which consists almost entirely of coarse-grained barite (b), transmitted light.

South Carolina Geology (1993 for 1992), V. 35, p. 79-83.

PATHFINDER GEOCHEMISTRY FOR THE SOUTH CAROLINA GOLD DEPOSITS

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Abstract

Four gold mines in South Carolina have been brought into production since the mid-1980's. Multi-element geochemical data compiled from these deposits, adjacent country rocks, and soils indicate that subtle increases in the concentration of arsenic, molybdenum, chromium, silver, vanadium and, locally, base metals occur in association with gold mineralization. Weak changes of only twice background in the concentration of these elements may reflect mineralized alteration systems and can be useful as a positive indicator for gold occurrence in the Carolina slate belt.

Introduction

Exploration efforts in South Carolina have led to the development of four gold mines since 1985: Haile, Brewer, Ridgeway and Barite Hill (Figure 1). By the end of 1991, the cumulative gold production from these mines exceeded 650,000 ounces.

To date, only limited geochemical information for the South Carolina gold deposits has been made public. This study was undertaken to collect and present geochemical data for samples from the four mines and adjacent host rocks. Geochemical analyses of 194 samples were compiled and results for select pathfinder elements are summarized in Tables 1 to 5. Portions of the data were presented at the 1992 Geological Society of America Southeastern Section meeting (Cherrywell and Tockman, 1992).

Regional geology

The operating gold mines in the region are situated within the Carolina slate belt, a northeast-southwest trending feature which extends from Virginia to Georgia. The Carolina slate belt in central South Carolina is comprised of two major units, including a Precambrian to Cambrian predominantly volcanic sequence (Persimmon Fork Formation equivalent) and an overlying Cambrian sedimentary sequence (Richtex Formation equivalent). These rocks were folded and weakly metamorphosed to greenschist facies during the early to middle Paleozoic and later intruded by approximately 300-million-year-old granitic plutons (Fullagar and Butler, 1979). The region was deeply eroded from the late Paleozoic until the Triassic at which time basins were developed due to late Triassic faulting. Following a period of erosion, Cretaceous Coastal Plain fluvial sediments and Tertiary eolian sediments were deposited. These mostly unconsolidated sediments have been dissected during the current erosional cycle. Within South Carolina, most of the gold occurrences, including the Haile, Brewer, Ridgeway and Barite Hill

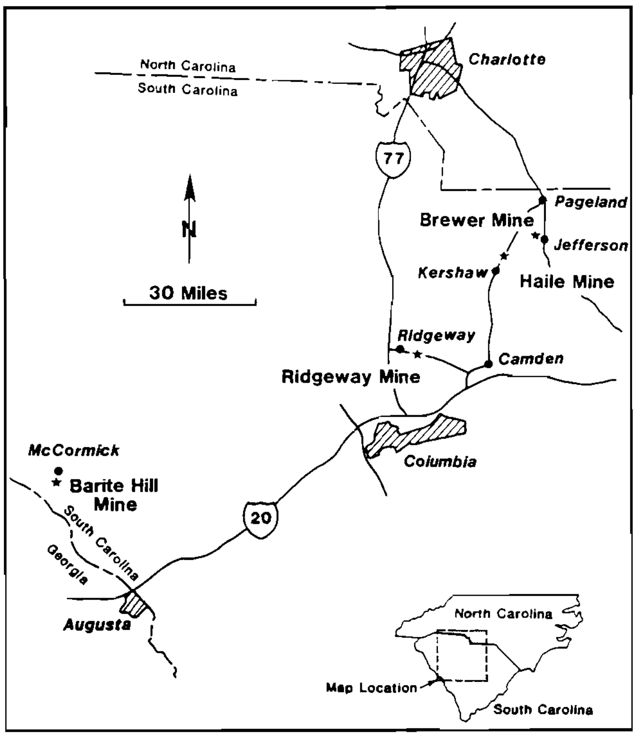

Figure 1. Locations of active gold mines in South Carolina.

deposits, occur at or near the contact of the felsic metavolcanics and overlying metasedimentary rocks.

Haile mine

Historically, gold was first discovered on the Haile property in Lancaster County, South Carolina in 1827. Renewed interest in regional gold prospects during the early 1980's led to the development and subsequent startup of current production activities at the Haile mine in 1985. Between 1985 and the end of 1991, 84,794 ounces of gold were produced at the Haile mine (Jones, 1992; Cherrywell and Tockman, 1992).

The Haile property consists of a series of orebodies located within a three-square-mile area. Speer and others (1992) report that gold mineralization occurs in both silica-pyrite zones hosted by metavolcanics and metamudstones and also in siliceous tectonic breccias within metavolcanics.

Soil geochemical surveys were completed in 1990 at the site of the current 601 orebody pit. Analytical results for these soil samples are presented in Table 1 along with analyses of oxidized ore zones from the 601 pit. The oxidized ore samples are comprised primarily of gossan and intensely silicified metavolcanics from the quartz-sericite-pyrite alteration zone.

Brewer mine

Current production at the Brewer mine in Chesterfield County, South Carolina started in 1987 with initial reserves announced at 5.1 million tons grading 0.042 ounces gold per ton (Scheetz et al, 1991). Later reports by Farmer (1991) describe reserves of 6.9 million tons of oxide ore at 0.035 ounces gold per ton along with approximately 4 million tons of sulfide ore at 0.04 ounces gold per ton. From startup through mid-1991, over 116,000 ounces of gold were produced at the Brewer mine (Farmer, 1991).

Scheetz (1991) and Butler and others (1988) describe the Brewer deposit as a silica orebody developed within surrounding felsic metavolcanics. The most significant mineralization occurs in a multiple phase and silicified eruptive breccia body. Alteration grades outward from the silicic core to a pyrophyllite-andalusite-kyanite zone to a quartz-sericite zone and finally into unaltered metavolcanic rocks.

Extensive sampling of the Brewer mine was completed by Scheetz (1991) and select results are shown in Table 2. The Brewer geochemical analyses are for samples collected from the gossan zone, quartz-sulfide breccia mixed ore, and andalusite-quartz-pyrite breccia.

Ridgeway mine

Exploration at the Ridgeway property in Fairfield County, South Carolina commenced in 1979 and mining began in 1988. The reserves for the North and South deposits comprising the Ridgeway mine are 56.2 million tons at a grade of 0.032 ounces gold per ton (Galactic, 1989). A total of 444,249 ounces of gold were produced at the Ridgeway mine from startup through September, 1991 (Guest, 1991; The Mining Record, 1991).

The Ridgeway deposits appear to be situated along an east-west trending contact zone between felsic metavolcanics to the north and a metasedimentary sequence to the south. Kral (1989) reports that the ore occurs in alteration zones characterized by sericitization with a core of silicification, quartz veining and pyrite development.

Geochemical data pertaining to the Ridgeway North orebody are listed in Table 3 and consist of analyses

Table 1. Haile 601 orebody geochemical results.

	Oxide Ore		Soil	
	Range	Average	Range	Average
Au	0.725-1.2	0.97	0.365-0.78	0.57
Ag	0.2-0.4	0.27	<0.2-4	<0.2
As	80-220	133	30-125	78
Cr	42-137	77	62-156	102
Cu	9-30	16	21-37	29
Mo	25-50	33	3-47	27
Pb	12-50	27	20-80	37
V	6-10	7.3	31-48	41
Zn	2-10	5	22-46	31
Total Samples	3	3	4	4

Results in parts per million (ppm).

Table 2. Brewer mine geochemical results.

	Quartz-Sulfide Bx Average	Gossan Average	Andalusite-Quartz Pyrite Bx Average
Au	3.61	0.431	0.604
Ag	1.2	2	0.76
As	53	9	66
Cr	10.2	5	87
Cu	498	270	177
Mo	31	63	16
Pb	49	482	11
V	15	9	1
Zn	38	52	13
Total Samples	6	7	7

Results in parts per million (ppm).

provided to the South Carolina Land Resources Conservation Commission by the Ridgeway Mining Company. This information includes samples from Ridgeway North core holes intercepting primarily the quartz-sericite-pyrite sulfide ore zone. Results of a 1989 soil sampling survey along the roadways overlying and adjacent to the north pit also are shown.

Barite Hill mine

Current production at the Barite Hill mine in McCormick County, South Carolina began in 1991 and in excess of 5,500 ounces of gold had been produced by the end of 1991 (The Mining Record, 1992). The deposit's reserves are 1.66 million tons at a grade of 0.038 ounces gold per ton (The Mining Record, 1990). At Barite Hill, gold mineralization is associated with sericitic and quartz-pyrite alteration within felsic metavolcaniclastics and metasediments (Gunter and Padgett, 1988; Clark and others, 1992). The deposit is zoned and consists of a mineralized quartz-barite-pyrite core surrounded by pyritic and argillic altered barren rock. Massive sulfide lenses and veinlets occur locally at Barite Hill.

Barite Hill drill data was provided by Nevada Goldfields Inc. (Table 4). The results were compiled from nine drill holes and include 48 sulfide ore samples and 42 oxidized ore intercepts.

Barren host rocks

Sampling of unaltered Carolina slate belt rocks has been completed by Shelley (1988) and partial results are presented in Table 5. The results list background values for chromium, copper and vanadium in the Persimmon Fork metavolcanic sequence. Additionally, limited sampling of the unaltered metavolcanics and metasediments (argillite) was conducted by the authors.

Table 3. Ridgeway North orebody geochemical results.

	Sulfide Ore		Oxide Ore	Soil	
	Range	Average	Average	Range	Average
Au	0.45-3.76	1.19	1.16	0.01-0.555	0.147
Ag	0-3.7	0.62	0	<0.2-0.8	0.23
As	3-268	108	58	<5-75	27
Cr	14-88	45	33	4-39	16
Cu	7-41	17	7	<1-43	16
Mo	0-35	8.1	5	<1-20	4.5
Pb	3-17	8	7	2-16	7
V	23-156	58	77	5-70	31
Zn	4-110	23	9	3-23	9
Total Samples	36*	36*	1	12	12

Results in parts per million (ppm).
*Gold analyses for only 23 samples of sulfide ore.

Table 4. Barite Hill mine geochemical results.

	Sulfide Ore		Oxide Ore	
	Range	Average	Range	Average
Au	0.24-3.22	1.33	1.19-10.62	1.50
Ag	0.2-44	10.9	0.6-66	12
As	10-1185	186	35-375	236
Cr	8-139	61	9-137	76
Cu	16-7410	870	28-1800	322
Mo	2-283	38	<1-141	43
Pb	10-972	170	24-978	279
V	<1-10	2	<1-359	29
Zn	4-3130	283	<1-149	22
Total Samples	48	48	42	42

Results in parts per million (ppm).

Summary

The geochemical data from the unaltered felsic metavolcanics and argillite country rocks contain no detectable gold and only traces of silver, arsenic and molybdenum. The unaltered sequences do carry detectable amounts of chromium, copper and zinc with the data suggesting that the argillite has higher background values than the felsic metavolcanics.

Oxide ore from the Haile 601 pit shows a marked increase in gold, arsenic, chromium and molybdenum in contrast to the unaltered host rocks. Similar results were delineated in the Haile soil samples.

Analyses by Scheetz (1991) for the Brewer mine indicate an enrichment of gold, silver, arsenic, chromium, copper, molybdenum, lead and zinc in advanced argillic alteration and ore zones.

Based upon the geochemical data available, sulfide and oxide ore from the Ridgeway North deposit contained increased concentrations of gold, arsenic, chromium, molybdenum and vanadium. Silver values in the sulfide zone were elevated slightly. The Ridgeway North soil samples also had anomalous values of gold, arsenic and molybdenum. Vanadium in the Ridgeway North ore zones was significantly higher than the values obtained at the Haile, Brewer and Barite Hill mines.

Core samples of Barite Hill sulfide and oxide ore were enriched in gold, silver, arsenic, chromium, copper, molybdenum, lead and zinc. In comparison to the other South Carolina gold mines, Barite Hill contains significant massive sulfide mineralization, as is apparent from the copper, lead, zinc and silver results.

Mercury and antimony also are used often as signature elements when evaluating gold prospects in other regions. Analyses for mercury were completed for samples from the Haile, Brewer and Barite Hill mines and the host rocks. Results were consistently at or below the 1 part per million (ppm) detection limit and, therefore, are inconclusive. Antimony analyses were available for all samples and generally were below a 5 ppm detection limit. However, Barite Hill samples did

Table 5. Carolina slate belt rocks geochemical results.

	Felsic Metavolcanic		Felsic Metavolcanic	Argillite	
	Range	Average	Average	Range	Average
Au	-	-	<0.005	<0.005	<0.005
Ag	-	-	0.4	<0.2	<0.2
As	-	-	<5	<5-5	<5
Cr	5-21	12	8	29-43	36
Cu	0-19	11	14	5-92	54
Mo	-	-	<1	<1	<1
Pb	-	-	20	<2	<2
V	0-102	38	11	27-35	31
Zn	-	-	28	70-104	93
Total Samples	23	23	1	4	4

Results in parts per million (ppm).

contain numerous antimony anomalies which ranged from 10 to 160 ppm. Traces of antimony also were identified in the Brewer and Ridgeway North samples.

Conclusion

In addition to gold and silver, the most significant pathfinder elements when examining Carolina slate belt prospects appear to be arsenic, molybdenum, chromium and vanadium. Anomalous concentration of base metals and antimony also can be present as observed at the Barite Hill and Brewer mines. Subtle variations of only twice background in the concentration of these signature elements in soil, saprolite and rock samples can represent alteration and related gold occurrence.

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